PB84-168970

Restoration of Failing On-Lot Sewage Disposal Areas

Pennsylvania State Univ., University Park

Prepared for

Municipal Environmental Research Lab.
Cincinnati, OH

Mar 84

U.S. Department of Commerce
National Technical Information Service
NTIS

PB84-168970

EPA-600/2-84-062
March 1984

RESTORATION OF FAILING ON-LOT SEWAGE DISPOSAL AREAS

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Cooperative Agreement CR807115-01

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U.S. ENVIRONMENTAL PROTECTION AGENCY
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TECHNICAL REPORT DATA (Please read Instructions on the reverse before completing)		
1. REPORT NO. EPA-600/2-84-062	2.	3. RECIPIENT'S ACCESSION NO. PB84 168970
4. TITLE AND SUBTITLE Restoration of Failing On-Lot-Sewage Disposal Areas		5. REPORT DATE March 1984
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) D.D. Fritton, W.E. Sharpe, A.R. Jarrett, C.A. Cole and G.W. Peterson		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS The Pennsylvania State University University Park, Pennsylvania 16802		10. PROGRAM ELEMENT NO. CAZB1B
		11. CONTRACT/GRANT NO. CR 807115
12. SPONSORING AGENCY NAME AND ADDRESS Municipal Environmental Research Laboratory - Cin., OH, Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268		13. TYPE OF REPORT AND PERIOD COVERED Final (8/79-7/83)
		14. SPONSORING AGENCY CODE EPA/600/14
15. SUPPLEMENTARY NOTES Project Officer: James A. Heidman (513)684-7632		

16. ABSTRACT

The objective of this project was to evaluate two rehabilitative techniques-water conservation and absorption bed resting--for restoration of failing on-site sewage disposal areas. Eleven homes with failing absorption areas were characterized and baseline water flow and septic tank effluent quality data were collected. Water conservation devices were then installed at maximum, moderate or minimum levels of predicted water reduction capability. At three sites effluent was also diverted to a specially designed alternate trench for 10 months which permitted the main absorption area to rest. Median in-house water reductions were statistically significant and ranged from 9.8 to 42.5%. Maximum levels of water conservation were generally successful in restoring failing systems while lesser levels of conservation were not successful. None of the three rested absorption beds malfunctioned in the 16 months since effluent flow was redirected to them However effluent is ponded in them and the level has been rising, suggesting that the effluent will have to be directed to the alternate trench at regular intervals in the future.

17. KEY WORDS AND DOCUMENT ANALYSIS		
a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Sewage Sewage Disposal	On-site sewage disposal Septic Tank Systems Oil Absorption Areas	
18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS (This Report) Unclassified	21. NO. OF PAGES 138
	20. SECURITY CLASS (This page) Unclassified	22. PRICE

EPA Form 2220-1 (9-73)

DISCLAIMER

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and asthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

The study described in this report evaluates the applicability of water conservation devices and alternative soil absorption systems as remedial measures for the correction of failing septic tank systems.

Francis T. Mayo, Director
Municipal Environmental Research
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ABSTRACT

Previous surveys of on-site sewage disposal systems on specific problem soils have frequently shown that 17 to 65% of the soil absorption areas are failing. Although the problem of failing systems has been recognized and documented, little research has been performed on possible alternatives to complete replacement of the soil absorption area. The objective of this project was to evaluate two rehabilitative techniques--water conservation and absorption bed resting--for restoration of failing on-site sewage disposal areas.

Eleven homes with failing soil absorption areas were identified in the Centre County, Pennsylvania region. At each home, the soil and site were characterized, and baseline household water flow and septic tank effluent quality data were collected. Water conservation devices were then installed in each home at one of three levels (maximum, moderate, or minimum) of predicted water reduction capability. At three of the minimum water conservation homes, effluent was also diverted to a specially designed alternate trench for 10 months which permitted the main absorption area to rest. Water flow and effluent quality data taken after conservation measures had been applied were measured for periods that were comparable to the baseline data period of measurement. In addition, the soil absorption areas were characterized by weekly measurements of surface conditions and effluent ponding levels for up to two years.

Median in-house water use reductions were statistically significant and ranged from 9.8 to 42.5%. The water use reductions were in accord with increases in most effluent quality parameters. Maximum levels of water conservation were generally successful in restoring failing absorption beds while lesser levels of conservation were not successful.

Absorption bed resting was also successful in restoring failing systems. None of the three rested absorption beds have malfunctioned in the 16 months since effluent was redirected to them. However, effluent is ponded in them and this level has been rising, suggesting that the effluent will have to be directed to the alternative trench at regular intervals.

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ACKNOWLEDGEMENTS

Without the faithful cooperation of the eleven homeowners involved in this project, this research could not have been accomplished. We will not name them individually, but we wish to acknowledge our appreciation for their patience and understanding as we dug up their yards and tramped through their homes.

We would also like to acknowledge the following individuals who contributed substantially to this project: Mr. Tom Williams, Mr. Dave Steele, Mr. Tim Ratvasky, Mr. John Stahl, Mr. Gilbert Osei-Kwadwo, Mr. Bob Breckenridge, Mr. Lyle Fisher, Ms. Mary Cannon, Ms. Sharon Waltman, Mr. Kevin Kinsley, Mr. Scott Saxe, Ms. Mimi Wutz, Mr. Jay Fackler, and Ms. Kim Tushek.

SECTION 1

INTRODUCTION

Surveys of on-lot-sewage disposal systems show that 17 (Hill and Frink, 1974) to 65% (Matelski, 1975) of soil absorption areas are failing. These failing systems result from an inability to recognize site limitations, a failure to understand the need for careful construction practices, and the use of water in excess of that which the mature absorption area can accept. Numerous examples of these general reasons for soil absorption area failure have been documented. Hill and Frink (1974) concluded that smearing of trench bottoms and sides during construction, inadequate absorption areas, and improperly performed percolation tests were causes of failure. Matelski (1975) suggested that inadequate design was at fault. Thomas et al. (1966), Bouma et al. (1974), Harkin and Jawson (1976) and others have shown that failure of soil absorption systems is due to the development of a biological clogging layer on the stone-soil interface. Machmeier and Mattson (1978) showed that inadequate permeability may be more important than clogging. Healy and Laak (1973) felt that 75% of all soil absorption systems failed due to hydraulic overloading as opposed to clogging. Despite the recognition and documentation of the problem of failing systems, little research has been performed on possible alternatives to complete replacement of the soil absorption area, the standard corrective procedure. In the search for a cheaper alternative, two technologies seem feasible. One is water conservation, and the other is resting of the absorption area.

Application of water conservation technology for the correction of failing soil absorption areas follows naturally from the reaction of many homeowners with malfunctioning systems who practice water conservation by modifying their water use habits. However, habit related water conservation is often short-term, while water conservation devices have the potential to reduce wastewater flow to the soil absorption area indefinitely. Wasteflow reductions to on-site sewage systems have been proposed and/or verified by Bennett (1975), Sharpe and Fletcher (1978), Siegrist et al. (1978), Kuhner et al. (1978), Cohen and Wallman (1974), Laak (1977), Baker (1980), and Rubin and Cogger (1982).

While a desirable impact of hydraulic load reductions on the soil absorption system has been postulated by many authors, actual quantified impact data are scarce. Sharpe and Fletcher (1978) estimated reductions in wasteflows of 52% for a selected combination of water saving fixtures and suggested that these reductions would allow directly proportional reductions in seepage bed and septic tank sizes. Siegrist et al. (1978) concluded that reducing flow volumes alone should allow for a proportional reduction in the soil absorption system but they indicated that the septic tank should not be

reduced in size because of suspected better treatment of peak flows with the longer detention time in the tank. They also stated that wasteflow reduction devices might extend the life of existing systems and alleviate surface discharge of sewage effluents in malfunctioning systems.

Baker (1980) measured an apparent flow reduction for a residential household in which 1.9 l per flush toilets and 1.9 lpm showers had been installed of 66% when compared to two other households occupied by families of similar size and age distribution. Baker also reported correction of existing failures and expanded use of existing systems in four situations; however, detailed analysis of the sites was not given.

Rubin and Cogger (1982) measured reductions in water use of 72% and 68% for two business establishments when air assisted toilets and spring activated faucets were installed. Seepage bed sizes were reduced 50% while septic tank sizes were not changed from conventional sizes. Sharpe (1979) measured a 40 percent reduction in wasteflow to a camp septic tank soil absorption system and showed increases in the concentrations of most wastewater constituents following water conservation device use.

The effective operation of soil absorption systems depends upon the ability of the wastewater to infiltrate into and percolate through the soil. Accumulation of organic material on the stone-soil interface causes a decrease in rate of water movement from the absorption system. The decrease in water movement is greater for soils with large pores and least for soils high in clay (Thomas et al. 1966). With the increased knowledge of the nature of the clogging phenomena and its influence on effluent flow have come proposals for reducing or eliminating the clogged layer. Soil absorption bed resting is one of the proposed methods for rehabilitating a system.

Those studies related to resting as a proposed rehabilitation technique include Thomas et al. (1966) who exposed a clogged layer, which had been formed on a large experimental sand column by the intermittent application of septic tank effluent, to air. Rapid recovery of infiltration rate occurred during the first 23 days of resting with a much slower recovery continuing for another 100 days. Bouma et al. (1974) considered a dual bed soil absorption system. One bed would be used while the other bed was rested. Loading would be sized to clog each bed during the resting of the other bed. They suggested that clogging materials would have ample time to decompose in a resting period of six months. Machmeier and Mattson (1978) performed a test of alternating beds which was intended to demonstrate the beneficial effect of resting. They needed to use the two beds simultaneously, however, because the ability of the soil to accept the flow was inadequate.

The objective of this project, then, was to evaluate these two rehabilitative techniques which may be less costly than construction of a new drainfield for restoration of failing on-site-sewage disposal areas. In order to accomplish this overall project objective, there were six subordinate objectives as follows:

a. To develop and evaluate field methods which may be used to screen

on-lot-sewage disposal failures for those which may be corrected with water conservation and/or absorption bed resting.

b. To document dwelling occupant characteristics, wastewater generation, and soil and site conditions.

c. To determine the ability of existing water conservation hardware to correct on-lot-sewage disposal malfunctions.

d. To evaluate the feasibility of using a small auxiliary soil absorption area to rest the main drainfield and restore its capability to absorb effluent.

e. To document, under conditions of actual use, the wastewater reduction possible with water conservation hardware and characterize wastewater quality changes which occur and homeowner acceptance of devices used.

f. To determine whether or not water conservation and/or absorption bed resting restored the failing system.

SECTION 2

CONCLUSIONS

1. Surface symptoms of a malfunctioning system were not an adequate indicator of those systems which could be corrected by water conservation. Soil permeability and age of malfunction were identified as additional important indicators of the malfunction severity.

2. Of the 11 failing on-site soil absorption systems investigated in detail, three were judged to have failed because of low soil permeability. The rest were judged to have failed because the effluent soil interface was clogged or otherwise compacted and smeared causing an infiltration rate below that required to handle the input volume of effluent.

3. Maximum level water conservation devices--consisting of air assisted toilets, front loading automatic washers, low flow shower heads (7.6 lpm at 345 kPa), and faucet flow control aerators (1.9 lpm for bathrooms, 9.5 lpm for kitchens)--were successfully used to reduce the severity of septic tank-soil absorption system malfunctions for systems which were marginally failing and formerly successful.

4. Water conservation devices reduced the peak hydraulic loads to all systems receiving maximum level water conservation devices.

5. User acceptance of the water conservation devices was very good. Maintenance problems were minimal on all devices except the water pressure toilets. The cost of water conservation device refit was generally less than that of replacing the entire soil absorption area or constructing a smaller alternate soil absorption area.

6. Small, carefully designed and dosed trenches can be used to provide disposal of septic tank effluent for periods during which an existing but malfunctioning absorption field is rested. Three malfunctioning absorption systems which had failed due to biological clogging were rejuvenated by complete resting for 10 months. The permanence of such rejuvenation appears to be greater than 16 months for each of the three sites.

7. Three homes with maximum water conservation devices produced water use reductions of from 27.3 to 42.8%. Moderate conservation levels produced water use reductions of from 14.7% to 36.7% while minimum conservation produced reductions from 10.0 to 33.1%. Reductions

above 20% were statistically significant at the 5% level of confidence.

8. Concentrations of most septic tank effluent pollutants were significantly increased after the installation of water conservation equipment. However, maximum water conservation appeared to reduce the daily load of organics discharged to the soil absorption system.

9. Both water conservation devices and absorption bed resting were shown to have the potential to restore a failing soil absorption area under appropriate conditions.

SECTION 3

RECOMMENDATIONS

1. The field procedure which was proposed for evaluating malfunction severity should be field tested.

2. Cheaper methods of extending and thus increasing the soil absorption area or of providing an alternative soil absorption area need to be developed which save the existing absorption area for future use.

3. A strong correlation found in this study between TOC and COD, ammonia-N and TKN, and ortho-P and total P indicates that the simpler analysis of the two should be used in future characterization studies of septic tank effluent.

SECTION 4

SELECTION OF SYSTEMS FOR THE STUDY

In order to execute the research, 12 failing on-lot-sewage disposal systems were needed. Initially, the Pennsylvania Department of Environmental Resources and local Sewage Enforcement Officers were contacted but it was found that no lists of homeowner inquiries about failing systems were kept other than those requiring immediate legal action. Next, advertisements were placed in two small-town newspapers. These advertisements resulted in numerous inquiries from homeowners with failing systems. Best results were obtained when a definite incentive for the homeowner was indicated.

A list of potential sites based on phone conversations was then compiled (see Table A-1 in Appendix A). These homes were visited by one or more of the project personnel to verify that a failure indeed existed and to eliminate sites where surfacing effluent represented more than 50% of the household wastewater production. These site visits were also used to eliminate systems which had likely failed because of a high water table, to select as wide a variety of soil characteristics as possible, and to evaluate the potential difficulties, both social and material, to the implementation of the project. After a home had been selected for the study, each owner was given a participation agreement (see Appendix B) which explained in detail the work planned at their residence. Each participant was required to sign the agreement before individual home-related activities started.

Using the above procedures, 12 homes (see Appendix C) located in Centre County, Pennsylvania were identified for the project. A summary of the characteristics of the 12 sites is shown in Table 1. Each selected home was given an identification number as shown in the first column of Table 1. These numbers will be used throughout this report to identify the experimental sites. The homes selected represented a range of characteristics with two to five family members per household and one to three baths with corresponding small to large overall size of the house. Statistics which help describe the family members are given in Table 2. In general, the homes were occupied by families with both parents working and with older children.

Most systems were very young to moderately young (two to 13 years) and most of the failures were relatively persistent in that many homeowners had been having problems for more than a year. Malfunctions at those sites where no age of malfunction is listed were probably of similar age except sites 6, 8, and 11 which may have been more recent (a matter of months). Most systems used a bed for the soil absorption area which is common construction practice today in Pennsylvania. As we investigated the sites, we found that three (sites 4, 7, and 12) had some sort of seepage pit in

TABLE 1. CHARACTERISTICS OF THE 12 SITES SELECTED FOR INTENSIVE STUDY

Site	Family Members	No. of Bedrooms	No. of Bath	Age of System in 1979	Age of Malfunction in 1979	Size of Tank	Size of Field or bed	Effluent surfacing
				(Yrs.)	(Yrs.)	(liters)	(meters)	
1	4	4	2	8	1 1/2	3780	7.6 x 12.2m bed	Yes
2	5	3	1	9	1 1/2	1890	6.1 x 12.2m bed	Yes
3	4	3	2 1/2	4	3	3780	6.1 x 13.7m bed	Yes
4	5	4	2	13	2	3780	13.7 x 0.6m trenches (3) Pit at end.	Yes
5	2	3	1F 2H	2	1 1/2	3780	6.1 x 15.2m bed	Yes
6	4	3	3	2	-	3780	6.1 x 12.2m bed	Yes
7	4	3	2	8	-	3780	1.0 x 2.0 m seepage pit	Yes
8	5	4	2 1/2	6	-	3780	7.6 x 13.7m bed	Yes
9	2	3	1	5	1	3410	7.3 x 12.8m bed	Yes
10	4	4	2	9	2 1/2	5680	12.2 x 0.6m trenches (4)	Yes
11	2	—	1 1/2	5	-	3780	5.5 x 13.7m bed	No*
12	5	3	1	9	-	1890**	9.8 x 0.4m trenches (2) 4.3m Deep pits at ends (1.0 x 2.0m)	Yes

* Backs up in the house.

**Metal tank was completely filled with solids and was rusted beyond repair. Kitchen and laundry discharges bypassed tank and flowed directly to soil absorption system. Tank was replaced by 3780 liter concrete tank on September 25, 1980.

TABLE 2. DWELLING OCCUPANT CHARACTERISTICS FOR THE 11 SITES WHICH COMPLETED THE STUDY

Site	Occupant Number	Age	Sex	Percentage of Time Spent at Home	Occupation
1	1	38	M	60	Research Aide
	2	35	F	70	Sales Representative
	3	10	M	70	Student
	4	8	M	70	Student
2	1	41	M	66	Superintendent
	2	41	F	66	Teller
	3	19	M	66	Student living at home
	4	18	M	66	Student at home summer
	5	13	F	66	Student
3	1	33	F	60	Real Estate Agent
	2	37	M	60	University Professor
	3	7	F	75	Student
	4	8	M	75	Student
4	1	56	F	90	Housewife
	2	54	M	60	Research Aide
	3	18	M	50	Student
	4	19	M	40	Student
5	1	30's	M	60	University Professor
	2	30's	F	80	Housewife
6	1	40	F	62	Research Assistant
	2	39	M	62	University Professor
	3	14	F	54	Student
	4	10	F	62	Student
7	1	35	M	40	Administrator
	2	34	F	50	Academic Advisor
	3	9	F	50	Student
	4	5	M	50	Child
8	1	39	M	58	University Professor
	2	40	F	62	School Counselor
	3	15	M	75	Student
	4	13	M	75	Student
	5	7	F	75	Student
9	1	27	M	60	Supervisor
	2	27	F	60	Secretary
10	1	41	M	70	Research Psychologist
	2	39	F	75	Film Analyzer
	3	21	F	70	Student
	4	20	M	80	Student
12	1	41	M	70	Plasterer
	2	39	F	70	Secretary
	3	22	M	66	Laborer
	4	17	F	70	Student
	5	16	M	70	Student

addition to or instead of a more modern absorption area. At two sites (4 and 12), the seepage pit had been constructed in an attempt to solve the effluent disposal problem before this project started.

Eleven of the 12 sites were identified as malfunctioning by surfacing of effluent in the yard. Site 11 had an overflow in the basement toilet during peak wastewater flow periods. Since this home was withdrawn from the study before treatments were applied, little further information will be reported for it. On only one site (5) was effluent actually flowing off the yard area. Two of the sites (4 and 9) had intermittent effluent flow within the yard area which was directly correlated with peak water use. The rest of the sites were initially characterized by one or more very wet areas in the lawn with effluent ponded a few centimeters below the soil surface. Later in the study, sites 6 and 8 developed continuous surface ponding. Both homeowners replaced their systems as this study was nearing completion.

SECTION 5

SOIL CHARACTERISTICS AT THE SELECTED SITES

Because on-site soil absorption area behavior is highly dependent upon the basic soil properties at the site, a comprehensive characterization of each soil was performed. After the absorption area was located, a 1-m wide trench was dug to an approximate depth of 2 m. The length of trench varied from 2 to 3 m. The trench was located as close to the absorption area as possible without interfering with the effluent disposal process and in an area of soil typical of that on which the absorption area was constructed. The soil profile was then described according to standard procedures (Soil Survey Staff, 1951). These detailed descriptions are contained in Appendix D.

Each horizon in each soil profile was sampled for laboratory tests. Bulk samples were taken, sieved in the field to determine rock fragment distribution, and used to determine particle size distribution and textural class. Clods in triplicate were removed from each horizon and used to determine bulk density at the -33kPa matric potential and at oven dryness. Also determined in the lab was the Coefficient of Linear Extensibility (COLE) at -33kPa and -1500kPa water contents. The procedures used are described in detail by Ciolkosz and Pletcher (1974). Detailed soil data are contained in Appendix E.

In addition to the profile descriptions and standard characterization information, data were collected to measure the depth to a water table and the water flow capabilities of each site. Water table levels were measured both within the beds or trenches and outside of the absorption area for all sites. Levels were measured in holes formed by augering to a 1.5-m depth, where possible. After an appropriate time, the water level was measured in the auger holes.

Water flow capabilities were measured through the use of the traditional percolation test (Environmental Protection Agency, 1980) at three randomly selected points in the vicinity of the absorption areas and through the use of the shallow-well pump-in test (Boersma, 1965). Three measurements were taken at each site by first running the shallow-well pump-in test in 0.11 to 0.15 m diameter augered holes at depths ranging from 0.71 to 0.94 m. The holes were then enlarged, after four to seven days drainage had occurred, to a diameter from 0.14 to 0.26 m and a depth of 0.81 to 0.99 m and the percolation test was run. These data were combined with additional data to develop an empirical equation relating the percolation rate to the shallow-well pump-in hydraulic conductivity (Ratvasky, 1982).

The soils present at the sites represented a reasonable range of characteristics and approached the desired mix for the project. Selected characteristics are shown in Table 3 to facilitate a comparison of properties among sites. The 11 sites represented soil textural classes ranging from sandy loam to clay as shown by the textural class at the 1-m depth. Wide ranges in bulk density at the 1-m depth (1.23-2.08 g/cm^3) and of parent material (alluvium, colluvium, and residuum) were also evident. At the time the soils were sampled, only two sites (1 and 12) exhibited a water table. The occurrence of mottles with a chroma of two or less, however, indicates (Soil Survey Staff, 1975 and Simpson, 1979) a seasonal high water table during the warm season (temperatures >15°C). Sites 2, 5, 9, and 12 had mottles (chroma <2) within the top 2 m. The existence of high chroma mottles in all sites except 3, 6, and 7 indicate that most of the soils have wetness problems. A slowly permeable layer was identified at four sites (2, 5, 6, and 9) within the excavation depth. Three (2, 5, 9) of these four soils have percolation rates indicating low permeability.

The mean percolation rates at the sites ranged from 7 to 1217 sec/mm (3 to 515 min/inch). Three of the sites (2, 5, and 9) would fail most regulation limits due to low permeability while site 12 would likely require special designs due to excessive permeability. The mean (some sites had fewer than three measurements in the mean) hydraulic conductivity values show a similar relationship. Thus, from the point of view of soil characteristics, sites 2 and 9 would not be accepted under 1982 Pennsylvania standards due to the depth to mottles (chroma <2); sites 2, 5, and 9 would not be accepted, in addition, because of too low a permeability; sites 1 and 12 would be limited to an elevated sand mound design; and sites 3, 4, 6, 7, 8, and 10 would qualify for a conventional absorption bed or trench system.

Water table levels measured during the spring of 1980 (a drought year) at locations within and outside the absorption area are shown in Table 4. The effluent situation in the vicinity of the worst visible surface area at the site is shown in the first column. In all cases except site 11, which had effluent backing up into the basement toilet, effluent was at or near the surface or discharging (site 5) on the surface near the system. At site 7, the effluent level was somewhat lower during the time of these water level measurements. At site 9, effluent discharged from a vent during peak loading periods.

The results of measurements taken at three additional holes on each site are also shown in Table 4. These measurement locations were selected to evaluate, during the typical spring high water table season, the possibility that a seasonal high water table was influencing the system failure. In all cases, holes were augered to 1.5 m unless coarse fragments prevented going that deep. Several holes were augered when coarse fragment limitations were met and data recorded only for the deepest hole. Holes augered within the systems were used to verify the effluent level near the edge where the holes outside the system were being augered. In all cases, it was concluded that the soil outside the system was unsaturated and, in most cases, no free water was evident to the depth of the hole. Frequently the outside locations were within 50 cm of the nearest edge of the systems, indicating that the ponding inside the systems was limited to the beds or trenches. At site 3,

TABLE 3. SELECTED SOIL CHARACTERISTICS AT 11 SITES WITH FAILING ON-SITE-EFFLUENT DISPOSAL SYSTEMS. ALL DEPTHS ARE MEASURED FROM THE SOIL SURFACE AS IT EXISTED BEFORE THE SYSTEM WAS INSTALLED

Site	Textural Class at 1-m depth	Total bulk Density at 1-m Depth	Type of Parent Material	Depth at Sampling to				Mean Percolation Rate*	Mean Hydraulic Conductivity
				Water Table	Mottling		Slowly Permeable Layer		
					Chroma ≤2	Chroma >2			
		(g/cm^3)		(m)	(m)	(m)	(m)	(sec/mm)	(mm/hr)
1	loam	1.54	Sandy Limestone Residuum	>1.33	>1.33	0.35	>1.33	90	4.5
2	loam	>1.90	Local Alluvium over Colluvium	1.90	0.20	0.00	1.74	288	6.0
3	sandy clay loam	1.87	Dolomitic Sandstone Residuum	>2.30	>2.30	>2.30	>2.30	19	11.3
4	silty clay	1.52	Local Alluvium and Colluvium over Limestone Residuum	>3.00	>2.45	0.66	>2.45	38	6.5
5	silty clay loam	2.08	Shale Colluvium over Shale Bedrock	>1.80	0.94	0.32	1.55	1217	_***
6	sandy loam	1.78	Sandy Dolomite Residuum	>1.60	>1.60	>1.60	1.24-1.60	19	>20.0

(Continued)

TABLE 3. (continued)

Site	Textural Class at 1-m depth	Total bulk Density at 1-m Depth	Type of Parent Material	Depth at Sampling to					
				Water Table	Mottling		Slowly Permeable Layer	Mean Percolation Rate*	Mean Hydraulic Conductivity
					Chroma ≤2	Chroma >2			
		(g/cm^3)		(m)	(m)	(m)	(m)	(sec/mm)	(mm/hr)
7	clay loam	1.63	Colluvium	>2.25	>2.25	>2.25	>2.25	85	10.0
8	silty clay loam	1.61**	Alluvium and Colluvium over Limestone Residuum	>1.85	>1.85	0.40	>1.85	52	20.0
9	clay loam	1.89	Sandstone Colluvium over Calcareous Shale Residuum	>3.60	0.10	0.10	1.35	751	3.7
10	silty clay loam	1.56	Inter-layered Limestone Residuum	>2.70	>2.46	0.64	>2.46	28	8.7
12	clay	1.23	Made Land over Lacustrine Deposits on Limestone Residuum	2.00	1.80	1.63	>3.25	7	>13.0†

* 60 min/in = 142 sec/mm.
** Data missing at 1m. This value was the average of the horizons above and below the 1-m depth
*** This site was not run because of the large amount of coarse fragments.
† Clay at this site contained large vertical cracks.

TABLE 4. SUMMARY OF EFFLUENT AND WATER TABLE PONDING LEVELS (APRIL 24, 1980 TO MAY 22, 1980)

Site	Effluent Conditions at site of visual problem*	Specific Water Table Ponding Depths		
		Hole 1	Hole 2	Hole 3
1	Effluent at surface	Within system 0.33 m	Outside system >0.60 m	
2	Effluent at surface	Outside system >1.50 m	Outside System >0.90 m	Outside system >1.20 m
3	Effluent at 0.08 m depth	Edge of system 0.38 m	Outside system >0.90 m	Edge of system 1.05 m
4	Effluent near surface	Between trenches near discharge 0.25 m	Between trenches Uphill 0.60 m	Outside system >1.50 m
5	Effluent flows out side of bed at 0.60 m depth	Outside system >0.90 m	Within system >0.40 m	Within system >0.60 m
6	Effluent at 0.13 m depth	Within system 0.44 m	Outside system >1.20 m	Outside system >1.50 m
7	Effluent at 0.50 m depth	Outside system >1.10 m	Outside system 0.90 m	
8	Effluent at 0.18 m depth	Within system 0.55 m	Outside system >1.50 m	
9	Effluent at top of gravel at 0.44 m depth	Near edge >1.30 m	Outside system >1.14 m	Outside system >1.50 m
10	Effluent near surface	Outside system >1.50 m	Between trenches 0.70 m	Outside system >1.50 m
11**	Effluent at 1.47 m	Within system 1.47 m	Within system 1.32 m	Outside system >1.50 m
12	Effluent near surface	Outside system >1.50 m	Between trenches 0.70 m	Outside system 1.20 m

* Even though these data indicate no surface ponding at some sites, surface ponding was observed by project personnel at all sites except 11 during other visits.

** System buried at depth of 1.8 m.

the holes augered at the edge of the system were only 15-30 cm from the edge of the gravel and showed some mounding of ground water in the immediate vicinity of the system. It was therefore concluded that all systems were failing either because the effluent soil interface was clogged or otherwise compacted and smeared to lower the hydraulic conductivity or because the overall soil permeability was so low that effluent could not flow away from the system fast enough.

SECTION 6

RESTORATION OF FAILING ON-SITE SEWAGE DISPOSAL SYSTEMS USING WATER CONSERVATION

WATER CONSERVATION DEVICES

Material in the previous sections has documented the characteristics of the 11 sites that were used in the study. The material in this section documents the studies involving the use of water conservation devices. In reading this section, the reader is alerted to the fact that sites 1 through 8 were equipped exclusively with water conservation hardware while sites 9, 10, and 12 were equipped with minimal water conservation hardware in support of the resting treatments which will be described in Sections 7 and 8.

Water conservation devices were chosen to reduce wastewater flows by varying amounts for the homes in the study. All homes were provided with one of three levels of conservation. The different demonstration homes, devices, and expected levels of conservation are shown in Table 5. Water use was monitored for individual water using fixtures, outside hose bibbs, and the home as a whole. Meters were read before water conservation devices were installed during spring and summer of 1980 (April 9, 1980-May 9, 1980 for sites 1, 2, 3, 4, 6, and 9; June 3, 1980-July 3, 1980 for sites 5, 7, 8, 10, and 12) and after conservation devices were installed in the spring of 1981 (May 19, 1981-June 19, 1981) for all sites. Household water use was determined by subtracting outside bibb use from the total household use. At sites 4 and 6, unaccounted outside water use occurred. Total water use for these sites was obtained by summing the water use for showers, toilet flushing and laundry. A short-term continuous record of the water use at each site was obtained during the before and after measurement periods by installation of a flow meter and recorder on the service line at each site. Wasteflow was assumed to be equal to inside water use for this part of the study.

Visual observations of the surface of the soil absorption system were made two times each week for 10 weeks before the devices were installed. After installation, visual observations were made twice a week at first then only once a week for the duration of the project. Ponding levels in the soil absorption systems were measured twice each week from August 25, 1980 to December 19, 1980 and once each week from January 9, 1981 to December 1982. The distance down to the free water surface was measured from a reference point above the system. Therefore, the smaller the ponding level measurement the higher the effluent level in the system and the poorer its operation. Homeowner observations of the systems were also solicited via questionnaire in the second year of the project.

TABLE 5. CONSERVATION DEVICES INSTALLED AT THE 11 SITES USED IN THE STUDY

Site	Aerators	Shower heads[1]	Toilets[2]
Maximum[3] conservation level			
2[4]	Bath 1 - 5.7 lpm Kitchen - none	Bath 1 - Lovo	Bath 1 Microphor
4[4]	Bath 1,2 - 1.9 lpm Kitchen - 9.5 lpm	Bath 1 - Navy Bath 2 - Lovo	Bath 1,2 Microphor
7	Bath 1,2 - 1.9 lpm Kitchen - 9.5 lpm	Bath 1,2 - Nova	Bath 1,2 Microphor
Moderate[3] conservation level			
1	Bath 1,2 - 1.9 lpm Kitchen - none	Bath 1,2 - Lovo	Bath 1,2 pressure
5	Bath 1,2,3 - 1.9 lpm Kitchen - 1.9 lpm	Bath 1 -Nova	Bath 1,2,3 pressure
8	Bath 1,2,3 - 1.9 lpm Kitchen - 9.5 lpm	Bath 1,2 - Nova	Bath 1,2,3 pressure
Minimum[3] conservation level			
3	Bath 1,2,3 - 1.9 lpm Kitchen - 9.5 lpm	Bath 1,2 - Lovo	Bath 1,2,3 low flush
6	Bath 1,2,3 - 1.9 lpm Kitchen - 9.5 lpm	Bath 1,2 - Lovo	Bath 1,2,3 low flush
9	Bath 1 - 1.9 lpm Kitchen - 9.5 lpm	Bath 1 - Lovo	Bath 1 Dams
10	Bath 1,2 - 1.9 lpm Kitchen - 9.5 lpm	Bath 1,2 -Nova	Bath 1,2 Dams
12	Bath 1 - 1.9 lpm Kitchen - 9.5 lpm	Bath 1 - Lovo	Bath 1 Dams

[1]All shower heads 7.6 lpm (liters per minute) maximum at 345kPa except Navy (1.9 lpm).

[2]Pressure toilet (3.8 - 5.7 L per flush), microphor (1.9 L per flush), and low flush (13.3 L per flush).

[3]Designed levels of conservation were: 40+% for maximum, 20% for moderate, and 10% for minimum.

[4]White-Westinghouse front loading automatic washing machine installed April, 1981 and removed July, 1981.

Septic tank effluent quality data were collected from June 2, 1980 to August 20, 1980 before conservation devices were installed and from November 3, 1980 to February 18, 1981 (excluding December 17 to January 5) after conservation devices were installed. Septic tank effluents were analyzed for chemical oxygen demand (COD), total organic carbon (TOC), nonfilterable residue (Nonf res.), total Kjeldahl nitrogen (TKN), ammonia nitrogen (ammonia-N), total phosphorus (TP), orthophosphate (Ortho-P), Chloride (Cl) and pH for all sites. In addition, total and fecal coliforms were determined on the effluent from two sites with devices designed to produce maximum wasteflow reduction. All parameters were measured according to Standard Methods (Amer. Public Health Assoc., Amer. Waterworks Assoc., and Water Pollution Control Fed., 1975). Grab samples were taken from each of 11 sites two times per week for 12 weeks before and 12 weeks after conservation devices were installed. The samples were removed from the septic tank 15 to 30 cm under the surface of the liquid in the septic tank between the effluent baffle and effluent pipe. Samples were taken between 9:00 a.m. and 3:00 p.m. using a hand-operated suction pump. Each individual system was sampled at about the same time each day.

RESULTS AND DISCUSSION

Water Use/Wasteflow Reduction

The water use of sites before conservation devices were installed was compared with that after conservation devices were installed. Arithmetic mean values, confidence intervals, and probabilities are shown in Table 6 while Table 7 contains the results for median values. The median value was assumed to be the better parameter for analysis since the data were not normally distributed. Trends and conclusions, however, are similar whichever one is considered. Both are reported since previous literature has mainly reported means and assumed a normal distribution.

The data presented in Tables 6 and 7 show very clearly the impact of water conservation devices on the water use of the residences in the study. As expected, the three sites with maximum water conservation devices produced the greatest mean water use reductions with after water use from 27.3 to 42.8% less than for the comparable period the previous year. Moderate conservation sites showed mean water use reductions of 14.7 to 36.7% while the reductions in minimum conservation sites ranged from 10.0 to 33.1%. Tests for significant difference in the before and after means and medians showed that the water use reductions for the maximum conservation sites were highly significant. The moderate conservation sites, with the exception of site 1, also displayed significantly different water use after device installation. As the data in Table 7 indicate, site 1 had a very low mean per capita water use even before the installation of water conservation devices. The water using habits of this family were so frugal as to preclude large savings with moderate level conservation devices. Only one of the five minimum conservation sites had median water use that was significantly different after the installation of water conservation devices, although the difference for site 6 was very close to being significant. It is obvious from the data presented in Tables 6 and 7 that maximum and moderate level

TABLE 6. MEAN IN-HOUSE WATER USE BEFORE AND AFTER INSTALLATION OF WATER CONSERVATION DEVICES[1]

Site	Water Consumption (lpcd) Before[2] $\bar{x}$	95% CI	After[2] $\bar{x}$	95% CI	% Reduction	Probability $\bar{x}_{before} = \bar{x}_{after}$ ($\alpha = .05$)
Maximum						
2[3]	197	±19	118	±13	40.0	.0000
4[3]	131	±14	95	±10	27.3	.0000
7	191	±19	109	±22	42.8	.0000
Moderate						
1	97	±17	83	±15	14.7	.0964
5	239	±33	154	±28	35.6	.0001
8	248	±64	157	±36	36.7	.0072
Minimum						
3	273	±41	245	±55	10.0	.2043
6	254	±53	204	±34	19.5	.0560
9	259	±48	218	±47	16.0	.1030
10	207	±55	167	±36	19.3	.1103
12	199	±39	133	±23	33.1	.0024

[1]In-house use was determined by subtracting outside hose bibb use from total site use for each site except 4 and 6. There was additional outside bibb use at sites 4 and 6, therefore total in-house water use was determined by summing toilet, shower and laundry water use.

[2]Meters were read in the "before" period during spring and summer of 1980 (April 9, 1980-May 9, 1980) for sites 1, 2, 3, 4, 6 and 9; June 3, 1980-July 3, 1980) for sites 5, 7, 8, 10 and 12). The "after" period, with conservation devices installed, was monitored in spring 1981 (May 19, 1981-June 19,1981 for all sites).

[3]Sites 2 and 4 also had front-loading washers from April, 1981 to July, 1981.

TABLE 7. MEDIAN IN-HOUSE WATER USE REDUCTION USING WATER CONSERVATION DEVICES[1,2]

Site	Water Consumption (lpcd) Before M	Before 95% CI	After M	After 95% CI	% Reduction	Probability $M_{before} = M_{after}$ ($\alpha = .05$)
Maximum						
2[3]	203	175-215	117	96-134	42.5	<.0001
4[3]	129	118-159	94	81-104	27.0	.0001
7	184	171-218	113	87-139	38.4	<.0001
Moderate						
1	81	68-120	73	69-100	9.8	.1170
5	230	189-273	139	112-168	39.5	<.0001
8	223	173-277	131	108-174	41.5	.0063
Minimum						
3	243	219-298	214	162-293	12.1	.0931
6	214	181-285	188	153-246	12.4	.1099
9	220	185-301	184	165-227	16.0	.0557
10	181	126-231	125	101-183	30.8	.1348
12	172	152-227	1371	96-165	20.6	.0059

[1]In-house use was determined by subtracting outside hose bibb use from total site use for each site except 4 and 6. There was additional outside bibb use at sites 4 and 6, therefore total in-house water use was determined by summing toilet, shower and laundry use.

[2]Meters were read in the "before" period during spring and summer of 1980 (April 9, 1980-May 9, 1980 for sites 1, 2, 3, 4, 6 and 9; June 3, 1980-July 3, 1980 for sites 5, 7, 8, 10 and 12). The "after" period, with conservation devices installed,

[3]Sites 2 and 4 also had front-loading washers from April, 1981 to July, 1981.

water conservation devices significantly reduced water use at the study sites. Minimum level conservation sites showed only site 12 with significantly lower water use, but the probability of accepting the null hypothesis for the other sites in this group was also relatively low.

Effluent quality

The results of literature values for typical septic tank effluents from Otis and Boyle (1976) and Salvato (1972) are compared with the values before conservation for this study in Table 8. The values for COD, Nonf res., TKN, and Ammonia-N were higher than those reported by Otis and Boyle. The results of Otis and Boyle were from typical, normally functioning septic tank soil absorption systems. The higher concentrations of all pollutants could have resulted from conservative use of water already occurring in the households where soil absorption field failure had occurred. Chloride results were not reported by Otis and Boyle but were compared with Salvato's data. Two sites (5 and 6) were excluded from the calculation since they had chloride concentrations 10 times that of the other sites because of ion exchange (I/X) water softeners. If one assumes a similar increase in sodium concentration, the total dissolved solids (TDS) and sodium placed in the groundwater were considerably above that of systems without ion exchange softeners. In areas where there are large numbers of I/X water softeners disposing regenerate through soil absorption areas, groundwater degradation could result. Chloride results for sites without water softeners were less than the median values reported by Salvato.

The pH for the test sites and literature values were all near neutral. Literature values for TOC were not available. Total coliform values were an order of magnitude less than Salvato's median values. Fecal coliform values for the before data were less than those reported by Otis and Boyle. However, there was considerable spread in the data and only two sites were sampled.

Results of comparisons of effluent quality before and after device installation are discussed elsewhere in detail (See Appendix F or Cole and Sharpe, 1982). Conclusions from those studies are summarized here. It was found that concentrations of most septic tank effluent parameters were significantly increased at sites after installation of water conservation equipment. Those sites receiving maximum water conservation devices had the highest and most significant increases in septic tank effluent pollutant concentration. There was some evidence that organics removal in septic tanks as measured by TOC and Nonf res. was improved in those systems receiving maximum conservation equipment. Correlations between effluent parameters before and after installation of wasteflow reduction hardware were nearly the same, indicating that wasteflow reduction had no affect on the relationship between parameters. A strong correlation between TOC and COD, ammonia-N and TKN and ortho-P and total-P indicated that the simpler analysis of each pair could be substituted for the more difficult analysis in future comparison studies.

TABLE 8. SEPTIC TANK EFFLUENT QUALITY COMPARISON

Parameter	Study Homes[1] (before device installation)	Literature[1]
COD, (mg/l)	485	360[4]
TOC, (mg/l)	174	—
Nonf Res., (mg/l)	108	54[4]
TKN, (mg/l)	77	55[4]
Ammonia-N, (mg/l)	52	39[4]
Total P, (mg/l)	18	15[4]
Ortho P, (mg/l)	13	12[4]
Chloride, (mg/l)	45	80[3]
pH, (mg/l)	6.9	7.4[3]
Total Coliform , (MPN/ml)	62,000[2]	1,100,000[3]
Fecal Coliform, (MPN/ml)	1,100[2]	4,210[4]

[1]Arithmetic means except where noted.

[2]Geometric means.

[3]From Salvato (1972), (median values).

[4]From Otis and Boyle (1976).

Malfunction correction

The primary objective of the project was to determine if water conservation could correct soil absorption system malfunctions. The measures of a malfunction are quite varied and subjective. A soil absorption system was considered to be malfunctioning if effluent was visible on the surface, the soil above the soil absorption field was abnormally wet, or effluent was not draining properly from the house because of inadequate effluent absorption. The impact of water conservation devices on the malfunctioning septic tank soil absorption systems in this study was evaluated by several different methods. None of these methods alone was totally satisfactory, but, collectively, they allow a reasonably good assessment of device impacts.

Table 9 contains the results of observed soil absorption bed conditions for two comparable periods before and after device installation. Sites 9, 10 and 12 are omitted from this analysis because the soil absorption systems at these sites were rested by completely diverting effluent into alternate soil absorption areas. It should be pointed out that rainfall in the summer of 1980 was well below normal so that the comparisons shown are decidedly conservative.

The data in Table 9 indicate that maximum level water conservation devices improved existing malfunctions at the sites receiving this treatment. Only one of the moderate level conservation sites showed a similar improvement and neither of the minimum level sites showed any improvement. In the case of site 3, the homeowner reported that the malfunction was improved by the water conservation devices, and, in the case of maximum conservation level sites 2, 4 and 7, similar comments were received. However, the occupants at site 1 did not agree with the observations in Table 9. They reported no improvement in their malfunction after device installation. Of the eight homeowners with water conservation devices and no alternate soil absorption areas, four thought that the devices helped and four thought that they did not. All of the maximum conservation level sites reported that the devices helped which agrees with the observations of project staff reported in Table 9.

The soil absorption area effluent levels for maximum conservation sites 2, 4 and 7 are presented in Figures 1, 2, and 3. Data for all other sites are not shown because no effect of water conservation on effluent levels was evident. The data are contained in Appendix H. It is obvious from the data presented that ponded effluent levels were usually much lower at sites 4 and 7 after the water conservation devices were installed. This observation agrees with the more subjective evaluations presented in Table 9 and those of the occupants of these two sites. The data for site 2 are not as easily interpreted. Although effluent levels appear to be generally lower during the winter and spring following device installation, peak levels corresponding to malfunctions continue to occur. This result generally agrees with the subjective evaluations of Table 9 and comments of the homeowner.

In the period from April to July 1981, effluent levels rose sharply at all three sites in response to increased rainfall. Effluent levels began to decline through late summer and fall or during the winter of that year at all

TABLE 9. EFFECT OF WATER CONSERVATION DEVICES ON SEEPAGE BED FUNCTION

Site	Nonconservation - Summer 1980[1]										Conservation - Summer 1981												
	6/30	7/9	7/21	7/23	8/4	8/6	8/11	8/13	8/20	8/30	5/19	5/21	5/23	5/24	5/26	6/1	6/8	6/15	6/19	6/26	7/3	7/10	7/17
Maximum Conservation																							
2	1[2]	1	1	1	1	1	1	1	1	1	0[3]	0	0	0	0	1	0	1[4]	-[5]	1[4]	0	1	1
4	1	1	1	1	1	1	1	1	1	1	0	0	0	0	-	0	0	-	0	1	0	0	1
7	1	1	1	1	1	1	0	0	0	0	0	0	-	0	0	0	-	-	0	0	0	0	0
Moderate Conservation																							
1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	1	-	-	0				
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-	-	-	1				
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-	1	-	-	1				
Minimum Conservation																							
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1				
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-	1	1	1				

[1]Drought year.
[2]Indicates that either a malfunction occurred on that date or that there was evidence of one having occurred during the interim between observations.
[3]Indicates no sign of a malfunction.
[4]Rain on that date.
[5]Indicates no observation on that date.

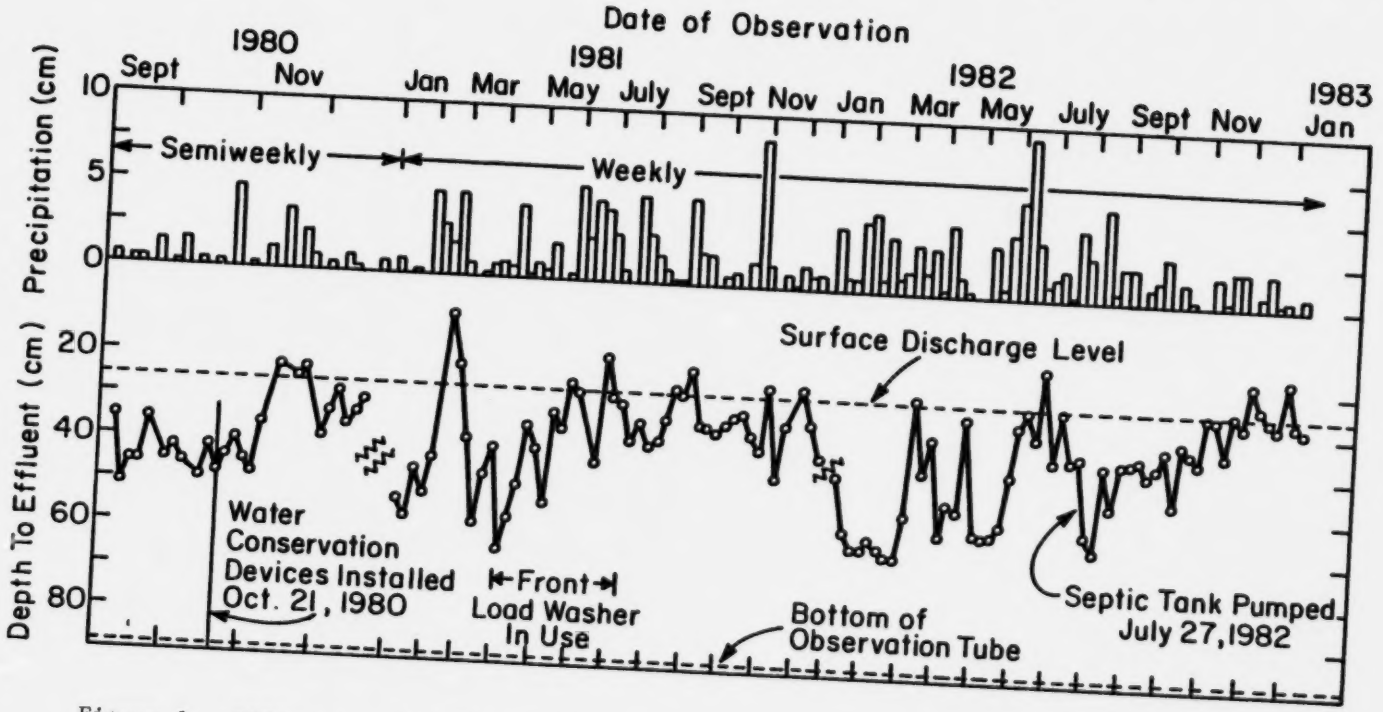

Figure 1. Effluent ponding levels in the soil absorption area and semiweekly or weekly precipitation for site 2.

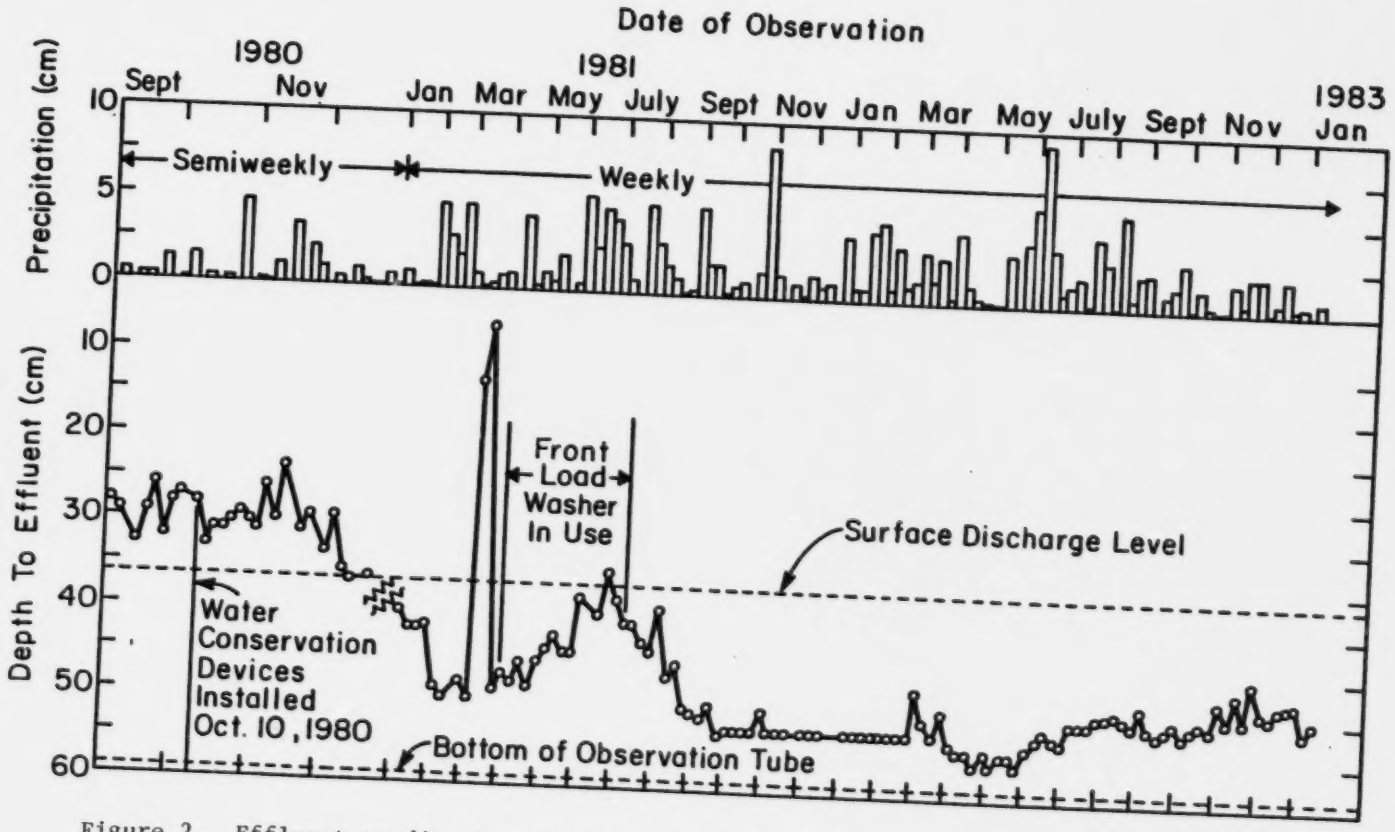

Figure 2. Effluent ponding levels in the soil absorption area and semiweekly or weekly precipitation for site 4.

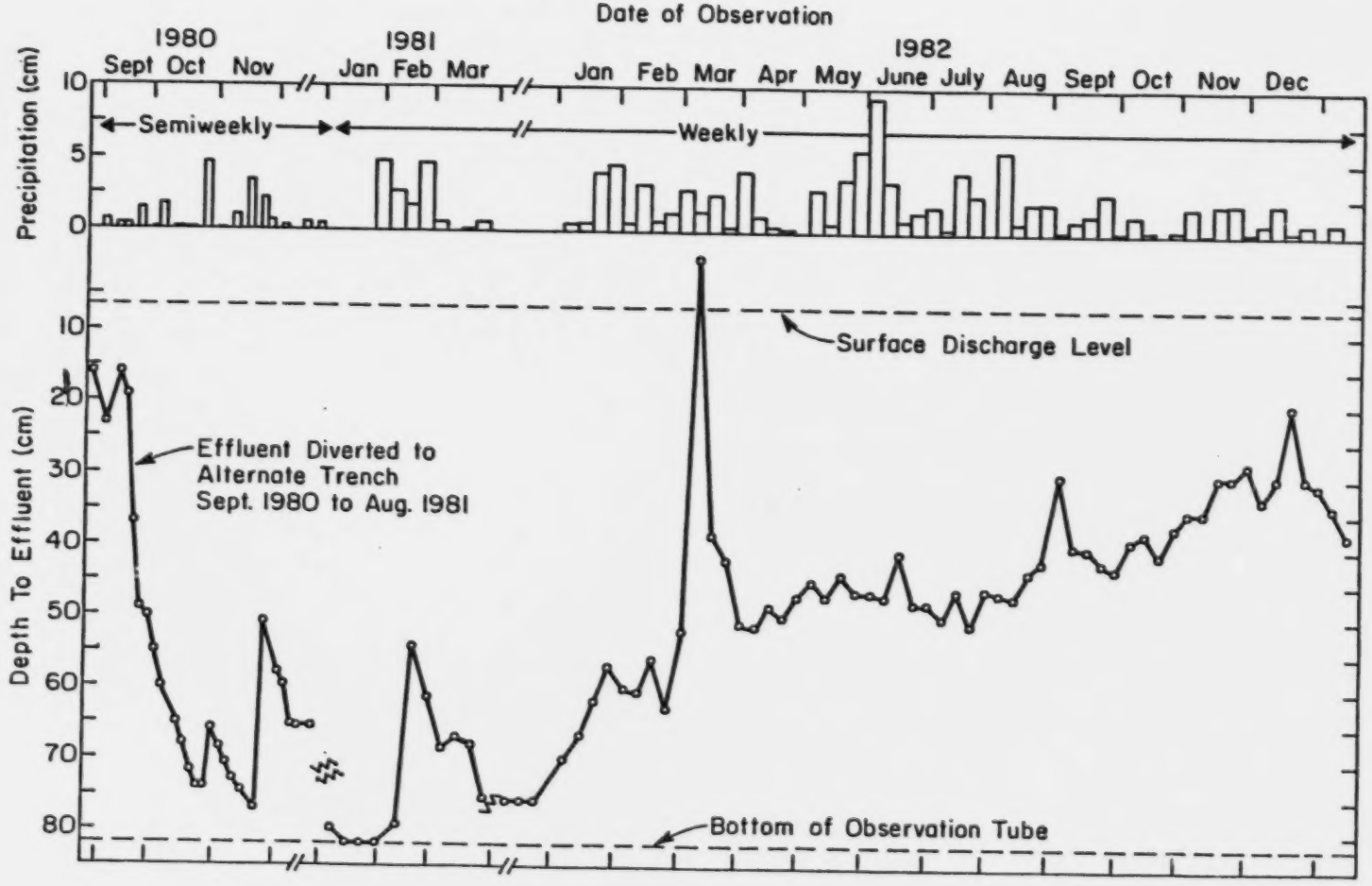

Figure 3. Effluent ponding levels in the soil absorption area and semiweekly or weekly precipitation for site 7.

sites. It would appear from the effluent levels in the soil absorption beds that short-term increases in precipitation or evapotranspiration and local drainage patterns play a significant role in determining short-term effluent levels in soil absorption systems. This fact notwithstanding, it is equally clear that average effluent levels were significantly lower following device installation at site 4. They were also initially significantly lower at site 7, but showed higher levels later, and somewhat lower during some periods at site 2.

Observations of the systems during data collection indicated that malfunctions after device installation were often only associated with peak loads on the system as a result of clothes washing. Observations of the systems during non-clothes washing periods revealed many fewer incidences of malfunction. Automatic clothes washers of the front loading type were added at sites 2 and 4 during April of 1982. These washers reduced laundry water use at site 2 by 47% and at site 4 by 14%. The result of these reductions was a marked decline in the frequency of malfunctions at these sites.

Frequent observations of the malfunctioning soil absorption system at site 7 after water conservation device installation indicated that no further malfunctions occurred.

Peak load reduction

The likely impact of water conservation devices on peak water use and concomitantly on peak household wasteflows is an important question. As has already been stated, field observations of malfunctioning on-lot systems indicated that malfunctions were often intermittent in nature. These intermittent malfunctions result because peak discharges exceed absorption capability.

A flow meter and continuous recorder were used to monitor water use in individual homes for short periods of time before and after water conservation device installation. Frequent difficulties were experienced with the measurement apparatus; consequently, the data obtained were difficult to interpret. Equipment failure and the relatively inflexible time schedule required by early device installation made it difficult to match before and after time periods so that equal weights could be built into the comparisons for different days of the week. However, the results of these measurements compare very favorably to those obtained by soil absorption area observations and effluent level measurements. The comparative data for time periods before and after device installation are shown in Table 10.

The hourly changes and the magnitude of the differences in flow rates for two of the maximum water conservation sites (4 and 7) can be seen in Figures 4 and 5. The data for site 2 are not available because of a recorder malfunction at that site. Sites receiving lower levels of water conservation devices, with the exception of site 8 (Table 10), did not show the consistent hourly reductions evident for the maximum conservation sites. However, for all sites, with the exceptions of 1 and 9, mean maximum hourly flow rates for a majority of the one-hour periods in a 24-hour day were reduced after installation of water conservation devices.

TABLE 10. THE MEAN NUMBER OF HOURLY MAXIMUM FLOW RATES WHICH WERE LESS THAN THOSE IN THE PRE-CONSERVATION PERIOD

Site	Hourly flow rates < Pre-conservation[1]
1	7
2	--[2]
3	20
4	23
5	15
6	20
7	21
8	22
9	12
10	15
12	17

[1]24 possible comparisons in a 24-hour day.

[2]No data due to equipment breakdown.

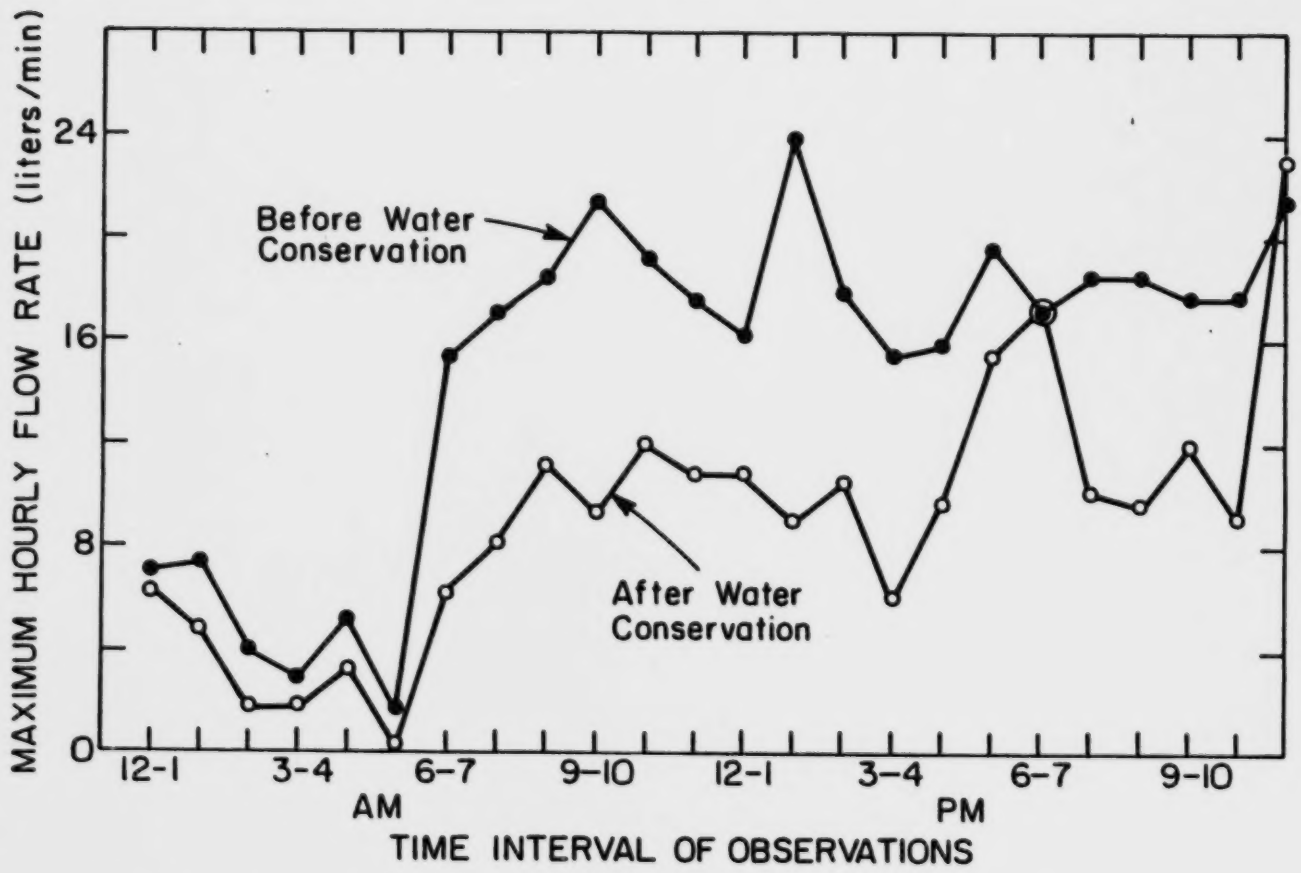

Figure 4. A comparison of the mean maximum hourly flow rates before and after installation of water conservation devices in house no. 4.

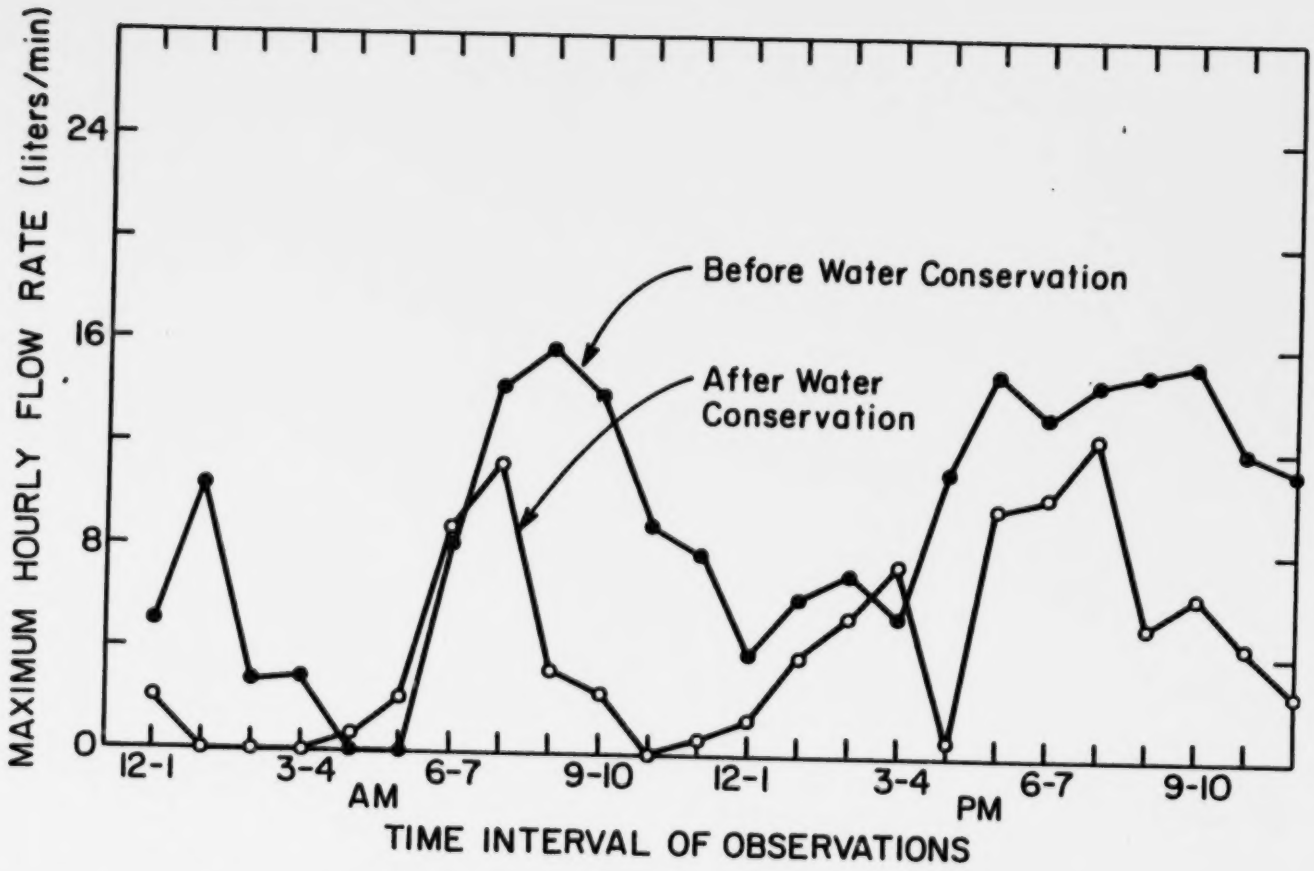

Figure 5. A comparison of the mean maximum hourly flow rates before and after installation of water conservation devices in house no. 7.

The impact of water conservation devices on peak water use was also analyzed by percentile rank comparisons before and after the installation of water conservation devices. Table 11 contains the results of this comparison. With relatively few exceptions, the water use was always less for a stated frequency when the water conservation devices were in place. The 100 percent frequency (all daily water use volumes that occurred in the measurement period were less than the stated volume 100 percent of the time) shows that in no case was the water use higher after the water conservation devices were installed. The difference in peak water use at various frequencies is often very large, indicating that the water conservation devices were very effective in reducing peak water use at sites under study.

Cost Effectiveness

The design of the research project was in part based on the premise that the remedial measures attempted should cost less than the current average cost of total absorption system replacement. Total system replacement costs, provided that such an option were possible, were estimated by project staff to be $1,500. The total costs of equipment and installation for each site receiving water conservation equipment are given in Table 12.

Most of the cost differences between sites within each conservation level are the result of differing numbers of bathrooms. The costs for sites 2 and 4 include $540 for the front loading automatic washing machines that were added to these homes after the start of the project. With this additional cost, the total cost of refitting site 4 exceeded the $1,500 maximum. Sites 5, 7 and 8 would also have exceeded this figure if automatic washers had been included in their refit schemes. The front loading automatic washers were essential to the correction of the malfunction of systems at sites 2 and 4, but not site 7.

All of the sites receiving moderate level conservation hardware (water pressure toilets) were refitted at less cost (Table 12) than any of the maximum conservation sites. However, the costs are not that much less (Table 12) and the water use reductions are more modest (Table 7). Considering the maintenance problems encountered with the toilets used, air assisted toilets were a better investment in this study.

The minimum conservation level sites can be broken down into those that had new toilets installed (3 and 6) and those that had plastic dams added to existing toilets (9, 10 and 12). The costs of new toilet purchase and installation made the refit at these sites many times more expensive than the ones receiving toilet dams. For sites 9, 10 and 12, water conservation device refit costs were minimal (Table 12). In most cases, water savings were small (Table 7) for sites with minimum conservation.

One possible way to reduce these costs is to outfit only one bathroom with the more expensive toilet systems. If this had been done at site 4, the cost of the refit could have been reduced by $378.30 to $1,249.55, well within the cost of other alternatives. Homeowner habit changes would be necessary if this option was to provide equivalent conservation.

TABLE 11. A COMPARISON OF WATER USE BY FREQUENCY OF OCCURRENCE WITH AND WITHOUT WATER CONSERVATION DEVICES

Site	Period[1]	Frequency (%) less than stated amount								
		0	5	10	25	50	75	90	95	100
		Water Use (liters per day)[2]								
Maximum[3]										
2	1	511	515	628	837	1014	1105	1298	1420	1431
	3	273	310	371	473	583	689	878	1011	1045
4	1	204	216	303	485	572	727	814	882	920
	3	110	189	273	291	386	443	519	534	553
7	1	—	204	462	583	731	886	1079	1120	1143
	3	4	26	102	291	454	591	742	757	765
Moderate										
1	1	121	170	250	265	322	526	617	784	916
	3	110	117	151	193	291	432	534	723	795
5	1	227	235	269	371	462	568	685	908	1030
	3	15	68	148	220	280	405	538	662	734
8	1	11	15	23	761	1117	1529	2389	3248	3380
	3	189	227	674	443	628	943	1673	1825	1953
Minimum										
3	1	560	583	647	844	973	1253	1628	2158	2574
	3	538	538	538	644	859	1200	1779	2177	2177
6	1	367	390	428	681	912	1370	2037	2256	2438
	3	333	344	416	602	738	1056	1385	1594	1635
9	1	144	201	310	367	439	655	890	1075	1136
	3	117	148	212	288	371	515	753	1105	1109
10	1	117	167	288	432	723	1018	1794	2415	2559
	3	68	227	329	375	500	999	1230	1624	1688
12	1	390	397	416	662	863	1257	1590	2362	2582
	3	167	197	254	291	545	678	829	1045	1132

[1]Water use periods before conservation period (1) and after conservation period (3). Before period is for spring and summer 1980 (4/9-5/9 for homes 1, 2,3,4,6 and 9; 6/3-7/3 for homes 5,7,8,10,12). After period is for spring of 1981 (5/19-6/19 for all homes).

[2]Water use was determined by subtracting outside hose bibb use from total household water use; in the case of houses 4 and 6, there was additional, unmonitored outside bibb use, therefore in house water use was determined by summing toilet, shower, and laundry water use.

[3]Conservation level.

TABLE 12. WATER CONSERVATION EQUIPMENT AND INSTALLATION COSTS IN 1980 DOLLARS

Site	Labor Cost	Equipment Cost[2]	Total Cost
Maximum			
2	$104.00	$1,248.19($708.19)[1]	$1,352.19($812.19)
4	154.00	1,473.85($933.85)	1,727.85($1,087.85)
7	181.00	984.36	1,165.36
Moderate			
1	56.00	641.90	697.90
5	76.00	967.26	1,124.87
8	121.00	1,003.87	1,124.87
Minimum			
3	76.00	294.67	370.67
6	76.00	294.67	370.67
9	0	18.67	18.67
10	0	41.75	41.75
12	0	18.67	18.67

[1]Costs without automatic front loading washer machine ($540).

[2]Costs of individual items in 1980 dollars were: pressure toilet, $309.37; microphor toilet, $661.79 (includes: toilet, $301.30; compressor, $195.50; installation kit, $44.99; air filter $65.55 and pressure reducing valve, $54.45); conventional water saving toilet, $98.22; toilet dams, $5.00;Nova showerhead, $8.25; Lovo 1 showerhead, $5.50; 1.9 lpm Chicago Faucet faucet-flow control, $3.85; 9.5 lpm American Std. faucet-flow control, $3.11; faucet aerator adaptor, $1.85.

Another important consideration that deserves mention is the savings in other resources and associated cost benefits to individual homeowners. It should be remembered that water and energy costs will also be reduced and should be included with the benefits of the refit to assist in amortization of the required equipment. The replacement of the automatic clothes washer with a new one also has additional benefits, the significance of which depends upon the age and maintenance history of the unit replaced. A detailed analysis of these additional benefits is beyond the scope of this report.

User Acceptance

In order to ascertain the attitudes of users to the water conservation devices used in the study, a list of questions was developed. The list of questions was distributed to each site and responses were obtained from all residences participating in the study. Only one set of responses was obtained from each site, and it was assumed to be the consensus of all those in residence at that site. The major results of this opinion survey are listed in Table 13.

All devices were well received by individual homeowners with the exception of faucet aerator-flow controls and Navy showers. Homeowners were weighted toward the negative side on faucet aerator-flow controls with seven reporting that they thought the device was either poor or fair and five reporting it to be excellent or good. The Navy shower was rejected in two homes during a brief pretest period and conditionally accepted in a third home where it was little used during the study. All remaining devices used showed a majority of responses in the excellent and good categories with air assisted toilets drawing excellent ratings from all three homeowners using that device.

In a related question, six of the homeowners surveyed indicated that they had modified their habits to use less water and five indicated they had not changed their water using habits. It was not possible in this study to completely separate water conservation device effects from habit changes that occurred incidental to device installation. None of the study participants indicated that they had changed their water use habits to use more water.

TABLE 13. USER OPINIONS OF WATER CONSERVATION DEVICES

Device	Number of Households Rating Service by Category			
	Excellent	Good	Fair	Poor
Air assisted toilets	3	--	--	--
Water pressure toilets	--	2	1	--
Conventional water saving toilets	1	1	--	--
Dams	2	--	1	--
Showerheads (standard)*	6	5	--	--
Faucet aerator-flow controls	3	2	4	3

*Navy showerheads were rejected by 2 sites and accepted but little used in a third site during the test. No other sites were given the Navy showerhead.

SECTION 7

ALTERNATE ON-LOT TRENCH SYSTEM WITH DOSING

TRENCH DESIGN

Three of the 11 sites used (9, 10, and 12) in the study were used for the resting treatment. During the resting treatment, effluent was diverted from the original failing soil absorption area to a specially designed alternate trench. Since the design of this alternate trench is new, it is described and evaluated in this section.

The trenches (see Figure 6) were essentially standard trenches with 100 mm of limestone sand on the trench bottom. The sand had a saturated hydraulic conductivity of 440 mm/hr; its gradation curve is shown in Figure 7. The sand was covered with 150 mm of 2B-limestone gravel with the distribution lateral placed above the gravel. A layer of untreated building paper separated the gravel and distribution lateral from the trench backfill material. The cost of the alternate trench system is summarized in Table 14.

The septic tank effluent was pumped to each alternate trench by a 0.25 kW sewage pump (60 L/min at 4.9 m head) located in a 2.2-m^3 dose tank located after the septic tank and before the existing distribution field. A 50-mm diameter PVC schedule 40 transmission line carried the dosed effluent to the alternate trench where a 50-mm diameter PVC lateral, with 4.8-mm holes spaced 1.0 m apart, distributed each dose evenly over the level trench bottom.

The pumping system was designed to dose the trench after the accumulation of 400 to 500 liters of effluent. The actual dose volumes were 480, 430 and 450 L at sites 9, 10 and 12, respectively. After each dose, the effluent was given about one-half day to infiltrate. The infiltration rate was monitored at sites 9 and 10 by placing a FW-1 Belford float recorder on a 50-mm diameter observation port placed in the trench. Water level data from these trenches yielded the time of each dose, the depth required to store each dose and therefore the drainable porosity of the media in the trench, and the rate at which the effluent was infiltrating.

Each trench was sized to fit each site by using the best available physical parameters in a two-dimensional porous media flow model developed by Amerman (1976). The simulation was performed on the trench as a two-dimensional, steady-state layered system. Rainfall and evapotranspiration were not considered. The input parameters and boundary conditions are shown in Table 15. Two simulations were performed on each trench. Initially it was assumed that the sand layer had no impact on the flow dynamics, yielding a design based on soil-water flow characteristics only. The second

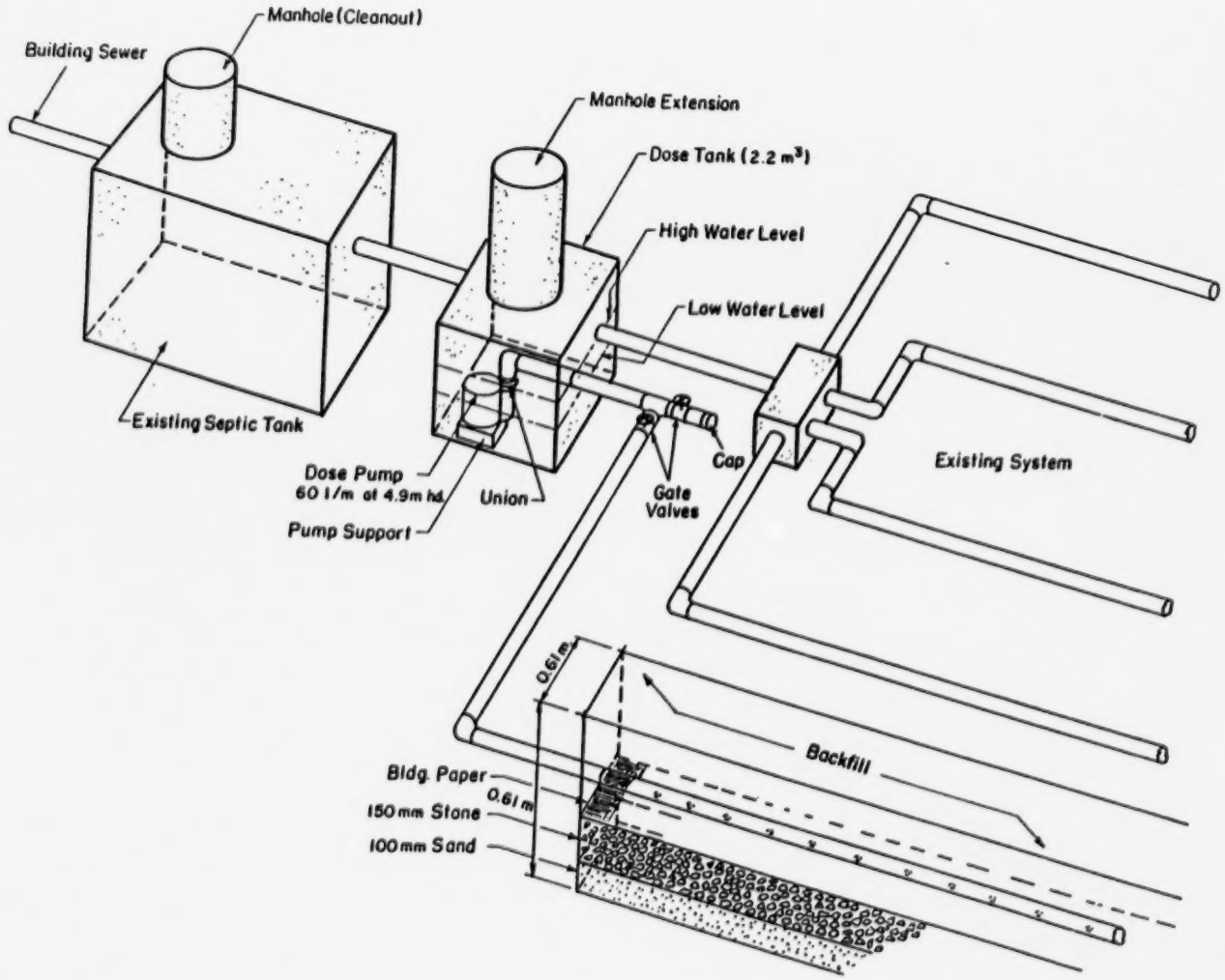

Figure 6. Alternate trench construction details.

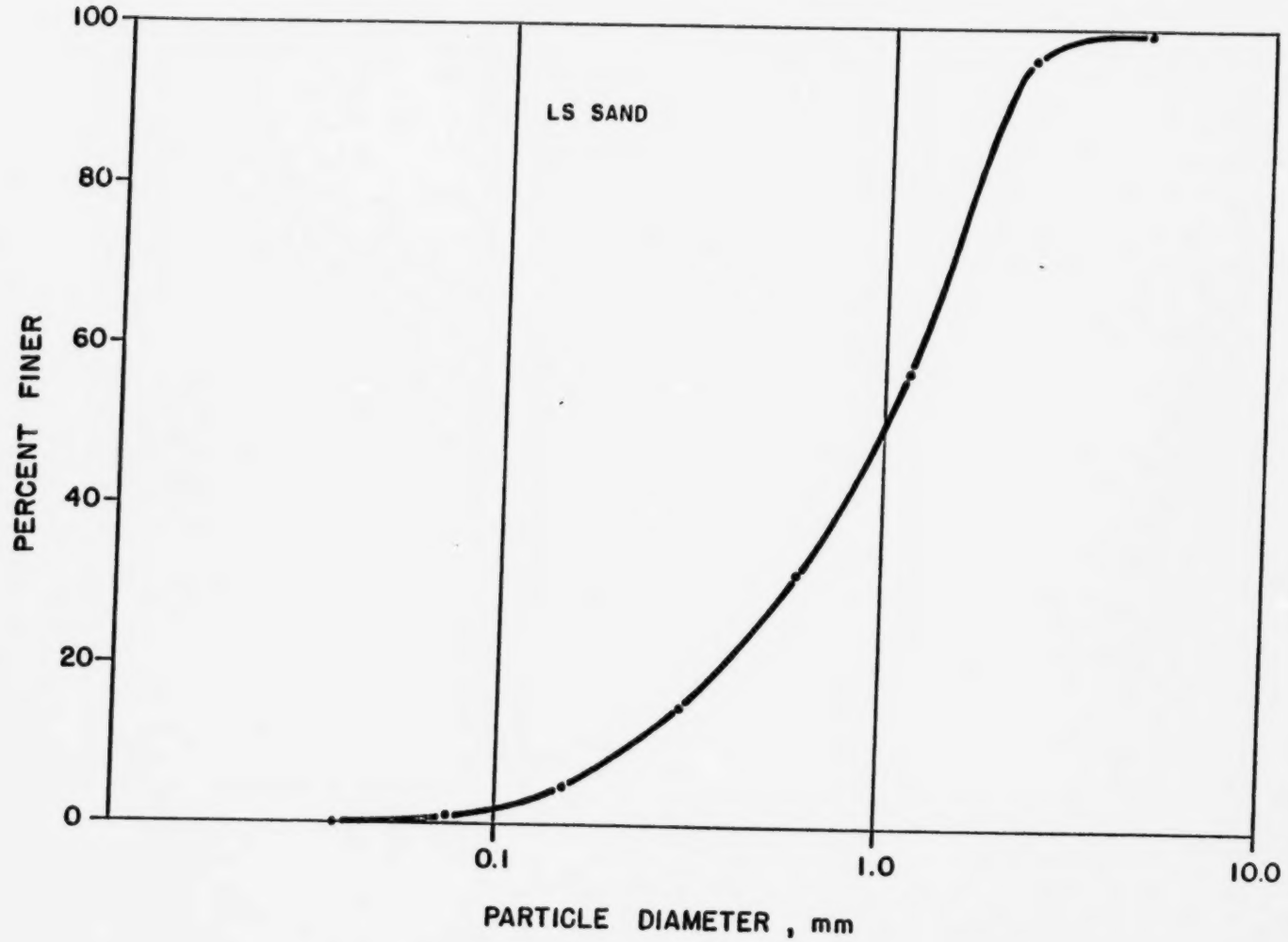

Figure 7. Gradation curve of sand used in alternate trenches.

TABLE 14. ACTUAL COST OF THE ALTERNATE TRENCH SYSTEM

System Design and Layout	$ 20
Pump Existing Septic Tank	65
2.2-m^3 Concrete Dose Tank	270
60 L/min, 4.9-m head - 0.25 Kw dose pump	167
Float Switching Assembly	44
Wiring of Dose Pump	150
6.4 Metrictions - 2B Gravel	38
3.6 Metrictions - 6 1/2 Limestone Sand	28
40 m - 50-mm Diameter Schedule 40 PVC Pipe	26
Excavating and Trucking, etc.	500
Plumbing	410
Landscaping	120
Alternate Trench Total	$1838*
Water Conservation Hardware	
1.9-L/min aerators in bathroom sinks 9.5-L/min aerator in kitchen 7.6-L/min shower heads Toilet dams	32
Total Cost of Treatment	$1870

*Under normal construction procedures the alternate trench could probably be installed for about $1100 with anticipated savings of $100 in the wiring of the dose pump, $300 in excavating and trucking, and $360 in plumbing.

TABLE 15. ALTERNATE TRENCH DESIGN SIMULATION PARAMETERS

Site	Hydraulic Conductivity	Soil Layers	Bottom Boundary	Water Usage
	mm/hr			L/day
9	1.3	1- 0 to 4.3 m	impermeable layer @ 4.3 m	606
10	9.2	1 - 0 to 2.0 m		1132
	9.2	2 - 2.0 to 2.7 m	impermeable layer @ 2.7m	
12	12.0	1 - 0 to 1.6 m	water table @ 1.6 m	1056
	12.0	2 - 1.6 to 2.8 m	impermeable layer @ 2.8 m	

TABLE 16. ALTERNATE TRENCH DESIGN SIMULATION RESULTS

Parameter	Site 9	Site 10	Site 12
Minimum Trench Area*(m^2)	8.5	4.4	3.2
Minimum Area of Clogged Sand+ (m^2)	12.1	22.6	21.1
Design Configuration (m)	0.7 x 21.0	1.2 x 21.0	1.2 x 21.0

*Results of first simulation without clogged sand layer.
+Results of second simulation with a clogged sand layer.

simulation kept the soil flow characteristics constant, but the sand layer was assumed to be clogged, having a hydraulic conductivity of 50 mm/day. The results of both simulations are shown in Table 16. Based on these results, the alternate trench was sized according to the area needed under conditions of a clogged sand layer, at each site (Table 16). The trenches were located on each site as shown in Figures 8, 9 and 10.

RESULTS AND ANALYSIS

The alternate trench systems were installed September 25 and 26 and November 4, 1980, at sites 12, 10 and 9, respectively. No effluent ponding was detected in any of the trenches until early January 1981 when a few millimeters of effluent were detected in the sand layer at sites 9 and 10. Between zero and 100 mm of effluent were observed in the trenches at these sites until about the end of February when the average depths began to increase slowly but continued to show a great degree of variability. In early April, float recorders were installed at sites 9 and 10 to provide continuous monitoring of the effluent ponding in the trenches. Table 17 is a summary of the data obtained from the water levels in trenches and the hydraulic analysis which followed.

Based on about three and one-half months of data, sites 9 and 10 show an erratic but gradual increase in the depth of effluent ponding in the trenches. During this period of record, the average depth of effluent was 186 mm at site 9 and 290 mm at site 10.

The measured (Table 17) rate of dosing to the trench at site 9 was 468 L/day which was an average of 0.98 480-L doses/day. The average rate of infiltration--calculated from the effluent ponding levels corrected for effluent inputs--from the trench into the surrounding soil was 527 L/day as compared to the design rate of 606 L/day, Table 17. Effluent ponding in the trench probably resulted from the inability of the hydraulic conductivity test employed in this study to adequately integrate the hydraulic properties of the area affected and/or the inability to correctly specify the boundary conditions for flow. It should be noted that these trenches were designed with the only factor of safety being the reduced water flow resulting from the water conservation hardware, with the intent to create a near failure situation. If ponding had not occurred, as at site 12, it would have been very difficult to evaluate the design parameters.

A similar evaluation of the data at site 10 shows that the average rate of inflow to the trench was 648 L/day or 1.51 430-L doses/day. The average rate of outflow from the trench was 751 L/day as compared with the design rate of 1131 L/day (Table 17). Again the difference between the design rate and the actual outflow rate is related to a problem of accurately evaluating the soil's hydraulic properties and the boundary conditions for flow.

Further evaluation of the data presented raises the question of why effluent ponding occurred in both trenches if the measured outflow rate exceeded the measured inflow dose rate. The magnitude of this problem can be seen in Table 17 by examining the gross mass balance for each trench. The calculations show that, over the period of record, there were 5309 L at site

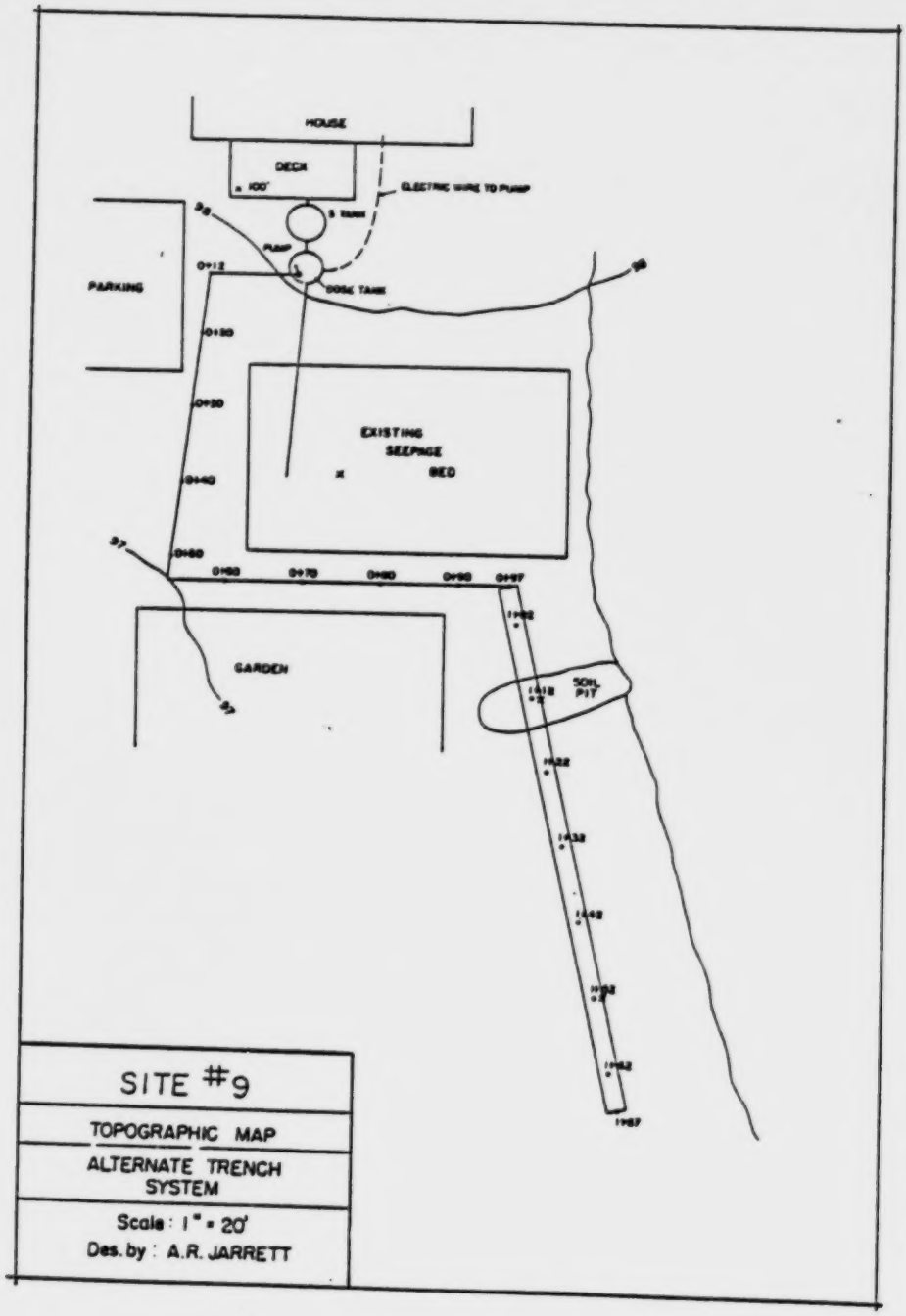

Figure 8. Topographic layout of site 9.

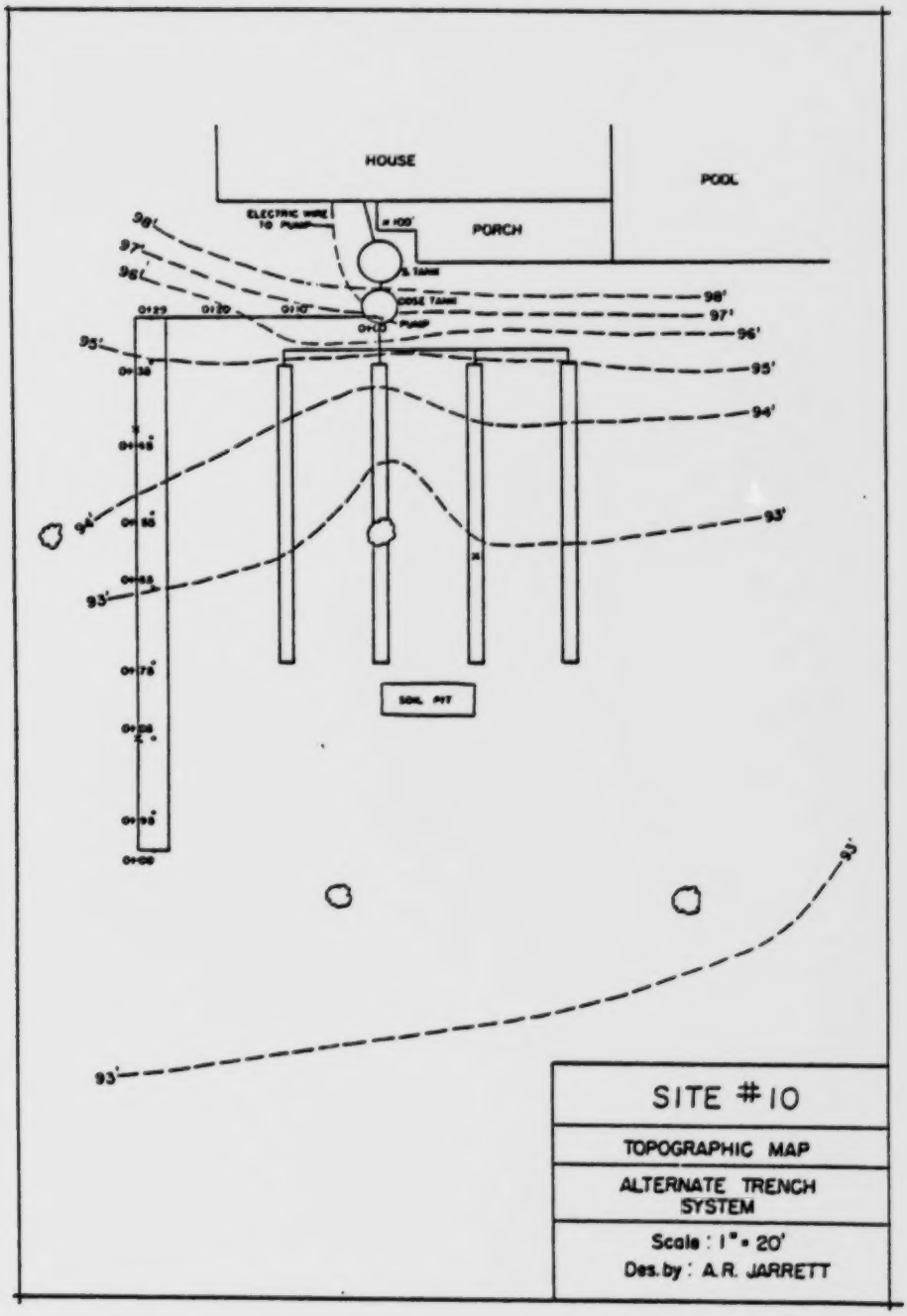

Figure 9. Topographic layout of site 10.

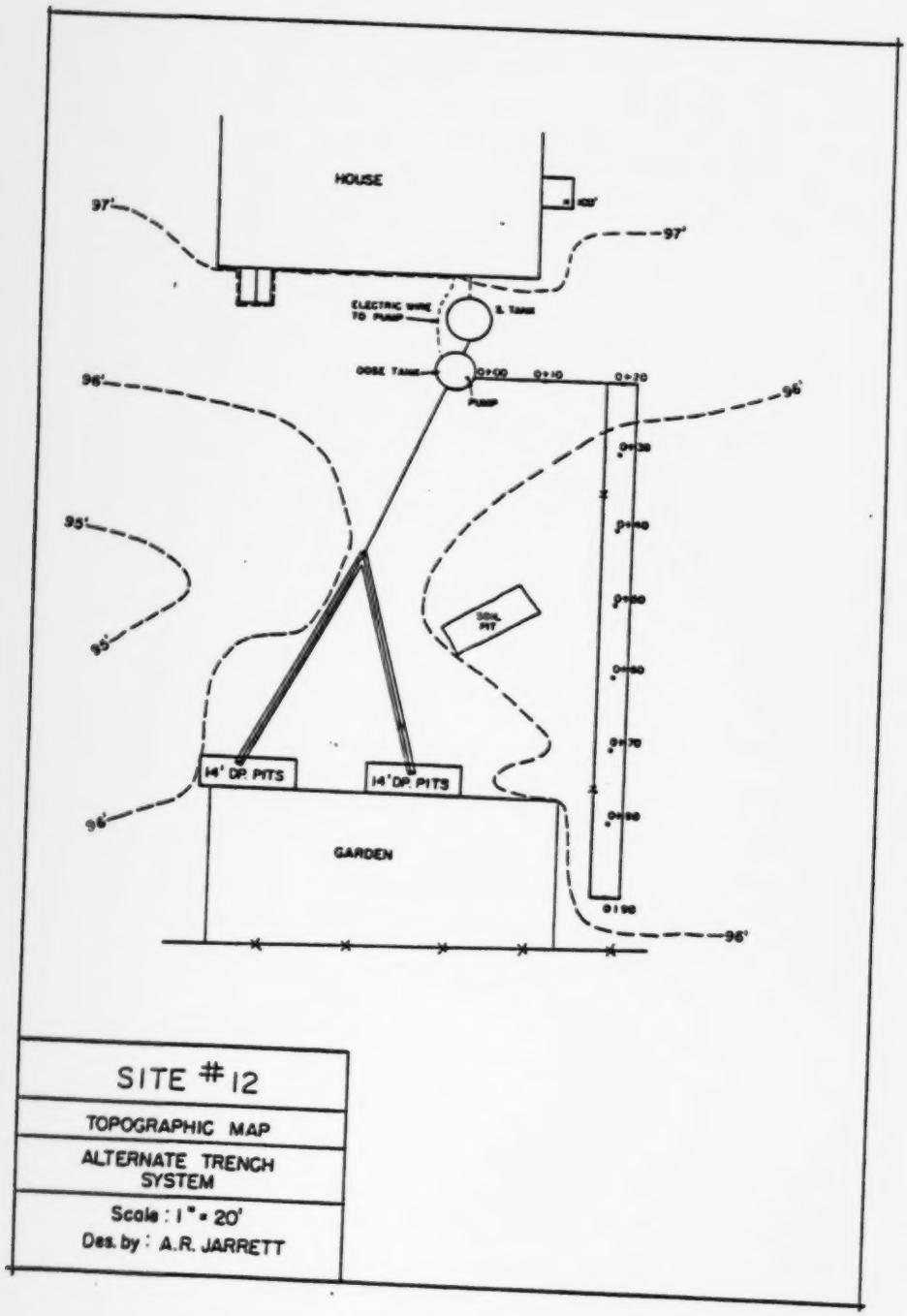

Figure 10. Topographic layout of site 12.

TABLE 17. EVALUATION OF HYDRAULIC PARAMETERS

Parameter	Site 9	Site 10
Number of days	81	67
Number of doses	79	101
Doses/day	0.98	1.51
Average depth of effluent in trench, d (mm)	186	290
and standard deviation	67	60
Volume/dose (L/dose)	480	430
Infiltration Area (m^2)	15.6 + .044 d	25.6 + .045 d
Average Infiltration rate from trench (L/day)	527	751
Design Infiltration rate from trench (L/day)	606	1132
Average effluent flow into trench (L/day)	468	648
Gross Mass Balance		
Volume into trench (L)	37908	43416
Volume from trench (L)	42687	50317
Volume stored in trench (L)	530	1160
$V_{out} - V_{in}$ (L)	4779	6901
Total Volume from other sources (L)	5309	8061

9 and 8061 L at site 10 which appeared in the trench from a source other than the dose tank. About half of this extra water can be accounted for by including rainfall but not evapotranspiration in the analysis. This additional water is believed to have come from surface and subsurface drainage water which moved into the trenches during and/or following rainfall.

An overall evaluation of the proposed design for the alternate trenches shows that it is very difficult to evaluate field parameters for inclusion in mathematical simulation models such as the Amerman (1976) model used herein. At all three sites, the Amerman model predicted smaller required areas than the clogged sand limitation. At two of the three sites, either the soil or the sand did not have the hydraulic capacity to conduct the waste flow from the alternate trenches. If the trenches had been sized 20% larger, ponding would probably not have occurred yielding a more successful design.

SECTION 8

EFFECT OF COMPLETE RESTING ON MALFUNCTIONING ON-LOT SYSTEMS

The same three of the 11 single-family residences (sites 9, 10, and 12 studied in Section 7) which had experienced surface malfunction of a seepage bed or standard trenches were selected for this part of the study. Each home had a septic tank and each of the systems had malfunctioned due to hydraulic overloading and/or the presence of a clog layer on the infiltrating surface. Initially, each home was instrumented with water meters to establish background daily water usage data (see Section 6 for details). Soils on each site were characterized (Appendices D and E and Tables 3 and 4) and water levels in the malfunctioning beds and trenches were monitored (see Appendix G). After six months of background data had been accumulated during the spring and summer of 1980, low-level water savings equipment was installed in the three homes.

All the effluent flow at the three sites was distributed to the alternate trenches (see Section 7) from October 1980 to mid-August 1981, giving the malfunctioning systems 283-, 325- and 324-day rests at sites 9, 10 and 12, respectively. The data collected (Figures G-9, G-10, and G-11) show that the old systems drained and returned to aerobic conditions within a few days after flow was diverted. During the first few weeks after the malfunctioning systems were drained, homeowners at sites 9 and 10 complained of malodorous gases escaping from their house vents. This condition was not reported at site 12. The authors believe that these gases were the by-products of biological stabilization in the malfunctioned old systems.

Water usage data obtained for a one month period during the summer of 1980 (before water conservation) and 1981 (after water conservation) showed a reduction in median per capita water usage of 16.0, 30.8 and 20.6% (see Table 7) at sites 9, 10 and 12, respectively. The larger than expected conservation effect was thought to be due to changes in water using habits during the study. The water use reductions were obtained at a cost per household of approximately $32 utilizing the 1.9-L/min aerators in bathroom sinks, 9.5-L/min aerators in the kitchen, 7.6-L/min shower heads, and toilet dams. The concomitant reductions in wasteflow undoubtedly contributed positively to the performance of the alternate trench systems.

In mid-August 1981, the dosing to the alternate trench systems was discontinued, causing the septic tank effluent at sites 9, 10 and 12 to flow to the previously malfunctioning soil absorption systems. It was hoped that during the 10-month rest period, the infiltration rate in the old systems would increase sufficiently to make it possible for the systems to function properly.

During the nine weeks after the effluent flow was returned to the old systems, float recorders monitored the depth of ponding in each system. Ponding at site 10 was minimal, averaging 5 mm depth with weekly fluctuations of ± 5 mm. Ponding depth at site 9 increased at the rate of 20 mm/wk during the first five weeks after flow started. During the next four weeks, the ponding depth remained at about 100 mm with weekly fluctuations of about ± 10 mm/wk. Ponding depth at site 12 increased at the rate of 25 mm/wk during the initial five weeks after flow started. Again, as at site 9, the average ponding depth continued at about 130 mm with fluctuations of about ± 60 mm/wk. The large degree of variability in the site 12 data was due to the small volume of storage available at that site relative to the other sites. The depth of ponding remained approximately constant for a four week period at both sites 9 and 12. This was probably due to very dry soil conditions caused by the lack of precipitation during this period.

Since the end of the initial nine week period reported above, ponding depths were recorded each Friday at noon. These data are plotted in Fig. 11 along with an eyefit regression line which shows the general trend and rate of increase for each site. Depth of ponding at site 9, after increasing rapidly during the initial nine weeks, slowed to a rate of increase of only 0.6 mm/wk during the next 22 weeks. The rate of increase at each of the other two sites was much greater showing rates of increase in ponding depth of 13 and 12 mm/wk at sites 10 and 12, respectively. These rapid rates of increase would lead one to assume that surface malfunctions are impending at sites 10 and 12. Most of the variability in the weekly data can be explained by periods of wet and dry weather. The large peaks in March were the result of extensive snow melt.

The complete set of data collected for these three sites is plotted in Figures G9, G10, and G11 (Appendix G) and includes another nine months of data from April 1982 through December 1982. As of January 13, 1983, none of the three absorption areas had malfunctioned. The data indicate, however, the very complex and almost unpredictable response that occurs in these ponding effluent levels. The ponding levels at site 12 have now leveled off and even declined slightly. Site 10 ponding levels indicate a continuing increase through early December with a decline starting in January of 1983. Site 9 ponding levels increased gradually through August of 1982, declined sharply through October 1982 and increased just as sharply through late November 1982 before again leveling off. Each ponding level measurement is integrating the effluent flow from the septic tank with infiltration, percolation, evapotranspiration,and subsurface drainage. The levels can be explained only if each of these factors is also monitored carefully. The data indicate that resting has restored the absorption area capability but also suggests that periodic resting will probably be needed in the future.

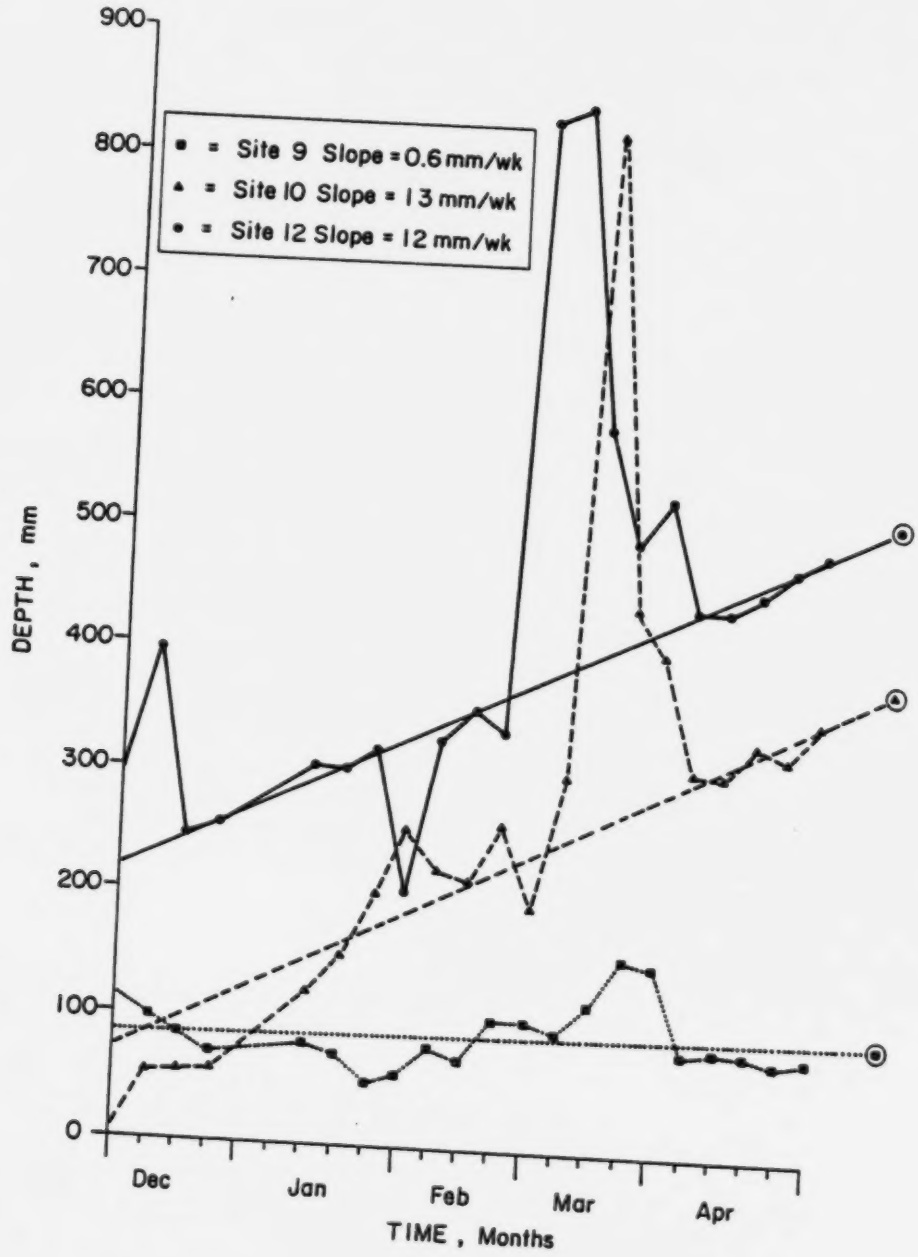

Figure 11. Depth of effluent in 3 rested soil absorption areas.

SECTION 9

SCREENING SYSTEMS FOR CORRECTABLE FAILURES

There are several possible courses of action to remedy malfunctioning septic tank soil absorption systems. Traditionally, a waste effluent collection system with centralized sewage treatment in a conventional sewage treatment plant has been the recommended solution to mass system failure. More recently, innovations in collection and treatment have become increasingly popular as corrective options. Even more recently, innovations in on-site treatment, such as composting toilets, have been promoted as solutions. The alternatives researched in this project were originally selected on the basis of their projected favorable costs versus the aforementioned alternatives.

The success of the water conservation alternative depends upon the severity of the malfunction to be corrected. Obviously, if the volume of septic tank effluent that is not accepted by the soil absorption system exceeds the reduction in the volume of effluent produced by water conservation devices, the water conservation alternative will be ineffective. Two essential elements in the prediction of the success or failure of the conservation method are an estimate of the severity of the malfunction (percentage of effluent not being accepted by the absorption field) and the predicted volume of effluent that can be reduced with water conservation hardware. The latter can be estimated with acceptable accuracy based on this project and others, but the estimation of the former is not accomplished so easily. However, the experience gained through this research project allows for the ordering of malfunction severity into the three broad classes based on surface symptoms--continuously wet surface soil, effluent ponded on surface soil, and effluent flowing over soil surface. All of the 11 sites studied had malfunctioning systems that exhibited at least one of these three symptoms. Maximum conservation devices were required for all symptoms to alleviate the malfunction with two exceptions where a moderate level of water conservation gave mixed results (i.e., some measures of improvement showing encouragement but others showing none). The surest alleviation of symptoms came from systems which were rested by a complete diversion of effluent to a new alternate system.

Equally important are the characteristics of systems which were not substantially improved by the water conservation treatments. Sites 6 and 8 had effluent ponded on the surface but seemed to have a minor malfunction at the time of initial evaluation. These two systems show the importance of including the age of the malfunction in any evaluation. Both systems turned out to be in the early stages of failure and became continually worse as time went on. By the end of one year, both had massive failures with effluent

flowing across the soil surface, giving greater than ten square meters of ponded effluent area. Sites 2 and 5 had very low permeability (percolation rates greater than 284 sec/min or 120 min/inch). Site 2 was the only site where maximum water conservation was not continuously effective in alleviating the surface symptoms of a malfunction. It would seem that while surface symptoms were not as severe as some, the soil just was not able to accept the effluent remaining after water conservation especially during peak flow periods. Thus again surface symptoms alone were not a reliable measure of severity of the malfunction.

The results obtained from this study indicate that for all severities of surface symptoms, moderate and minimum water conservation were unlikely to provide a definite alleviation of a malfunction. The results, although hardly conclusive, do indicate that maximum conservation devices can work. Unfortunately, the method of predicting the success of such treatments was not reliable. However, if the additional benefits of water and energy conservation are factored into the decision to select the water conservation device alternative, the uncertainties of success are less foreboding. In most situations, if the selection of water conservation hardware is done intelligently, it will be the least cost alternative. However, on the basis of the research conducted in this study and from a purely malfunction-correction viewpoint, the use of an alternate soil absorption system would be the surest method of correcting severe septic tank soil absorption system malfunctions. In any case, the results of this project indicate that the old system should not be abandoned because its function can be at least partially restored after a period of resting. Most likely the new system and old system will have to be used alternately as a dual bed system.

With the experience gained from this project, the following procedure for evaluating failing on-site soil absorption systems for malfunction is proposed. Since all systems which have surface malfunctions (the most common failure) are ponded, the level of ponding is a good measure of volume changes in the soil absorption system. If all water flow to the system is turned off for a short period of time to let the ponding level stabilize, then the ponding level and time can recorded. Then a known volume of water, small enough to avoid surface flow but large enough to produce an easily measured change in ponding level, should be added to the system through the home plumbing system. While this procedure hasn't been attempted, a volume equivalent to the daily use of the household would seem to be appropriate. Once the water is added, a new time and ponding level should be recorded. The ponding level should then be observed periodically until it returns to the level recorded before the water addition. The total time required for the added water to infiltrate would be noted and converted to a daily infiltration rate. Of course no further water use can be allowed during the measurement. The severity of the malfunction is defined as:

$$\text{malfunction severity} = \left(\frac{\text{water used per day} - \text{water infiltrated per day}}{\text{water used per day}} \right) 100$$

It represents the level of water conservation required as a percentage of the existing water use or, alternatively, the increase in the existing absorption

area required to bring effluent inflow into equilibrium with absorption area outflow.

The malfunction severity can then be calculated from the data as follows:

$$\text{malfunction severity} = 100\left(\frac{\text{Average daily water use} - \left(\frac{\text{Water added}}{\text{Time required for infiltration in hours}}\right) 24 \text{ hours}}{\text{Average daily water use}}\right)$$

Average daily water usage would have to be obtained from historical water use records for the household or from new measurements from an existing or newly installed total flow meter over a period of at least one week. Most likely, the best measure will result if the test is performed during the wettest season of the year.

If malfunction severity exceeds predicted wasteflow reduction by maximum conservation devices, minimum conservation devices and resting would be the indicated remedy for the malfunction. If malfunction severity is less than predicted wasteflow reduction, then maximum water conservation devices are indicated. In the former case, maximum water conservation devices could still be used if justified by water and energy conservation benefits.

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APPENDIX A

CHARACTERISTICS OF SURVEYED SYSTEMS

A list of potentially usable systems identified by homeowner responses to newspaper advertisements is shown in Table A-1. This list includes the 12 systems selected for this study as well as others which were seriously considered but not selected. Most of these sytems were visited by project personnel to verify the characteristics listed. Systems were rejected for use in the study if:

a. Failure was probably a result of a high water table.

b. The absorption system was of a unique design that would not be representative of a large number of failing sites.

c. The homeowner was already using water conservation without complete success but at a level which suggested further conservation might not be adequate. This reason was usually a result of the homeowner removing washwater from the absorption area and disposing of this water through surface runoff. We estimated that this may represent a savings of 30%.

d. The homeowner was already involved in a legal action with a contractor or other persons relative to the failure.

TABLE A-1. DESCRIPTION OF HOME SITES WITH FAILING SEPTIC TANK ABSORPTION FIELDS

Identification Number	Age of System (yrs.)	Baths	Family Members	Size of Field	Water Table	Seepage in Yard
SC1	13	2	5	9.8 x 10.4m	--	Yes
SC2	2	1 full 2 half	2	92.9m^2	--	Yes
SC3	--	1	--	--	--	--
SC4	9	1	5	6.1 x 12.2m	--	Yes
SC5	2	3	4	46.5m^2	--	Yes
SC6	12	1 1/2 no shower	4	--	--	Yes
SC7	8	2	4	--	--	Yes
SC8	1	1 1/2	2	--	High	No*
SC9	13	2	--	--	--	No*
SC10	--	--	--	--	--	No*
SC11	8	1	5	--	High	No*
SC12	3	2 1/2	4	--	--	Yes
SC13	--	2	4	--	--	Yes
SC14	8	3	8	--	--	Yes
SC15	9	1	5	--	High	Yes
SC16	18	1 1/2	2	22.9m long	--	Yes*
SC17	11	1 1/2	4	--	--	No*
SC18	6	2 1/2	5	--	--	Yes
SC19	5	1	2	--	--	Yes
SC20	9	1	5	--	--	Yes
SC21	9	2	4	--	--	Yes
W1	--	2 1/2	3	12.2 x 30.5m	--	No
W2	--	1 1/2	3	--	--	Yes
W3	20	1 1/2	3	15.2 x 30.5m	--	Yes
W4	7	1 1/2	4	4.6 x 13.4m	High	Yes
W5	Aerobic system		--	--	--	--
W6	--	2 1/2	8	--	High	Yes
W7	--	--	--	--	--	--
W8	6	1	5	--	--	Yes
W9	14	1	4	--	--	Yes
W10	22	1	2	--	--	--
W11	2	2 baths Duplex	6	--	--	Yes

*Effluent backs up in the house.

APPENDIX B

PARTICIPATION AGREEMENT

Between

THE PENNSYLVANIA STATE UNIVERSITY

And

HOMEOWNER: NAME_____

ADDRESS_____

_____

PHONE NUMBER_____

The homeowner whose name and address appears above agrees to allow his (her) home to be used in The Pennsylvania State University's research project "EPA Restoration". As a part of this agreement, the homeowner agrees to allow flow monitoring equipment to be installed on water lines and on toilets, showers, and clothes and dish washers. At daily or weekly time intervals, the homeowner agrees to allow project personnel listed at the end of this agreement access to the monitoring devices located in or near the home for the purpose of recording data. The time of each visit will be agreed upon in advance as suits the desires of the homeowner. The homeowner agrees to allow samples of effluent to be taken from the septic tank outflow to be analyzed.

At an appropriate time agreed upon by the homeowner and project personnel, the homeowner agrees to allow a set of water conservation devices to be installed in the home. The project personnel will select a set of water conservation devices for the home which, in

their opinion, are predicted to alleviate the soil absorption area malfunction being experienced by the household. Flow monitoring will continue after water conservation devices have been installed. At the request of project personnel, the homeowner will fill out questionnaires during the project regarding the water conservation devices installed in their home.

At an appropriate time agreed upon by the homeowner and project personnel, the homeowner agrees to allow a backhoe to enter the property and excavate pits, which will be used by project personnel to evaluate soil characteristics. The area of disturbance to the homeowner's property will be kept as small as practical. Project personnel will surround the pits with snow fence or cover them with plywood when project personnel are not present. All pits will be backfilled by project personnel with excavated soil as soon as measurements are completed. Project personnel will grade the soil surface, allow it to settle, regrade it, prepare it as a seedbed, and sow grass or vegetation of the homeowner's preference or provide remuneration to the homeowner to cover such costs. If conditions warrant in the opinion of project personnel, the homeowner agrees to allow a small auxiliary absorption area to be constructed on the property. The auxiliary absorption area will be used to rest the failing absorption area. At the request of project personnel, the homeowner agrees to allow the septic tank and/or the absorption bed to be pumped at the expense of project personnel. In addition, the homeowner agrees to allow instrumentation to be placed in, on, or near the absorption area. The instrumentation will be well

marked and cause as little disturbance to yard maintenance as practical.

At the end of this project which will occur on or about September 30, 1981, all water conservation devices and any auxiliary absorption area will become the property of the homeowner. All monitoring equipment will be removed unless cost of removal is greater than value of the equipment. In all cases, the homeowner may request that any or all monitoring equipment, water conservation devices, and auxiliary absorption areas be removed or restored to their previous condition. All yard areas will be restored to their previous condition or remuneration will be provided to the homeowner to cover such costs.

In addition to the water conservation devices, the homeowner will be paid $100 not later than September 30, 1981, for participation in this research project.

This agreement may be cancelled prior to September 30, 1981, upon thirty days' notice at the request of the homeowner. In such a case, the homeowner agrees that project personnel will be allowed to remove all installed equipment and devices and that the $100 payment will be forfeited. Project personnel may terminate this agreement at any time. However, if, except upon default under this agreement by the homeowner, project personnel terminate the agreement, the homeowner will retain all water saving devices and will be paid the $100 as if the agreement had been completed.

The homeowner acknowledges that the flow monitoring devices and the water conservation devices will be installed by plumbers or other persons who are independent contractors and not the agents or

servants of the University or project personnel, and that the University and project personnel shall not be responsible for the acts or omissions of such persons.

THERE ARE NO WARRANTIES, EXPRESS OR IMPLIED, AS TO THE MERCHANTABILITY OF ANY DEVICES OR EQUIPMENT USED IN THIS PROJECT OR AS TO THEIR FITNESS FOR ANY PARTICULAR PURPOSE.

Names and addresses of Project Personnel

Daniel D. Fritton, 318A Tyson Bldg.

Charles A. Cole, Capitol Campus, PSU
U. S. Route 230
Middletown, PA 17057

William E. Sharpe, Land & Water

Albert R. Jarrett, Ag. Engineering Bldg.

Gary W. Petersen, 311 Tyson Bldg.

Tom Williams, Land and Water

The signatories indicated below have read and agree to the terms of this document.

_____ _____
Homeowner Date

_____ _____
The Pennsylvania State University Date

APPENDIX C

Photographs of Systems

Used in the Study

Figure 1. Malfunctioning septic-tank absorption area shown in the front yard of site 1.

Figure 2. Malfunctioning septic-tank absorption area shown in the back yard of site 2.

Figure 3. Absorption area at site 3 which has a ponded low spot on the left side of the picture.

Figure 4. Absorption area at site 4. The malfunction occurs just in front of the plowed area near the white sign.

Figure 5. A photo taken from the absorption area showing where effluent flows between two trees at site 5.

Figure 6. Absorption area at site 6. Effluent surfaces near the bottom of the picture.

Figure 7. Absorption area in the back yard of site 7 with the malfunction indicated by the sunken dark area at the center of the picture.

Figure 8. Absorption area at site 8. Malfunction occurs at sandbox near the center of the photo.

Figure 9. Absorption area at site 9. Malfunction occurs during peak flow at the standpipe at the center of the photo.

Figure 10. Absorption area at site 10. Malfunction occurs where the tree shades the soil surface.

Figure 11. Absorption area at site 11. No seepage occurs at this site.

Figure 12. Malfunctioning area shown in front of the white sign as a dark area.

APPENDIX D

Soil Profile Descriptions of the Eleven Sites Used in the Study

Site 1

Described 8/6/80

This site occurs on an ENE facing convex slope of 14%, at an elevation of 354 m with a relief of 55 m over .2 km. This is a moderately well drained soil of moderately slow to moderate permeability, formed in sandy limestone residuum, with the upper horizons (Ap, B21, B22) developed in materials that had been perturbed by man. The profile was very moist when described.

Ap	0-6 cm	Dark grayish brown (10YR 4/2) silt loam; moderate medium granular and weak medium subangular blocky structure; friable, nonsticky, nonplastic; many medium roots; common, fine continuous random pores; neutral (6.8); abrupt smooth boundary.
B21	6-72 cm	Brownish yellow (10YR 6/6) loam mixed with many medium prominent very dark gray (10YR 3/1), and common fine distinct strong brown (7.5 YR 5/8) inclusions of clay loam; moderate to weak medium subangular blocky structure; friable to firm, nonsticky, slightly plastic; many medium roots; common, very fine discontinuous random pores; common, thin discontinuous mangans on some ped faces; slightly acid (6.4); gradual wavy boundary.
B22	72-107 cm	Yellowish brown (10YR 5/8) clay loam with common fine distinct very pale brown (10YR 7/3) and common fine faint strong brown (7.5YR 5/8) mottles; strong coarse subangular blocky structure; firm, slightly sticky, plastic; many medium roots; common, fine discontinuous argillans on ped faces; few, thin discontinuous mangans in pores; neutral (6.6); abrupt wavy boundary.
A1b	107-122 cm	Very dark gray (10YR 3/1) silt loam; strong fine granular and moderate medium subangular blocky structure; very friable, nonsticky, slightly plastic; many medium roots; many, very fine continuous random pores; slightly acid (6.2); abrupt wavy boundary.
A2b	122-142 cm	Light yellowish brown (10YR 6/4) loam; moderate coarse subangular blocky parting to moderate medium platy structure; firm, nonsticky, plastic; many medium roots; few, very fine discontinuous horizontal pores; slightly acid (6.4); clear wavy boundary.
B21b	142-158 cm	Brownish yellow (10YR 6/6) clay loam with common fine faint brownish yellow (10YR 6/8) mottles; moderate medium subangular blocky structure; friable, slightly sticky, slightly plastic; many medium roots; common, coarse and very fine continuous vertical pores; common, thin discontinuous argillans on some ped faces; common, thick continuous mangans in large pores, and common,

		thin continuous mangans on some ped faces; neutral (6.6); gradual wavy boundary.
B22b	158-193 cm	Brownish yellow (10YR 6/8) clay loam; weak medium prismatic and moderate coarse subangular blocky structure; friable to firm, slightly sticky, slightly plastic; few medium roots; few, very fine discontinuous oblique pores; few, thin discontinuous argillans on ped faces; few, thin discontinuous mangans in pores; neutral (6.6); gradual wavy boundary.
B23b	193-216 cm	Brownish yellow (10YR 6/6) clay loam with many coarse faint brownish yellow (10YR 6/8) and common fine distinct dark yellowish brown (10YR 4/4) mottles; moderate fine and medium subangular blocky structure; friable, slightly sticky, slightly plastic; few medium roots; many, very fine continuous horizontal pores; common, thin continuous argillans in some pores; slightly acid (6.4); clear wavy boundary.
Cb	216-240 cm	Brownish yellow (10YR 6/8) clay loam with common medium prominent dark yellowish brown (10YR 4/4) mottles; moderate medium subangular blocky structure; very friable, slightly sticky, nonplastic; few roots; many, fine and very fine continuous oblique and horizontal pores; slightly acid (6.4).

Additional Notes:

1) The depth to water table was 240 cm.

2) The B21 horizon is a mix of A and B horizon materials deposited as fill with debris from construction (wires, metal, etc.).

Site 2

Described 7/30/80

This site occurs on SSE facing convex slope of 3% at an elevation of 415 m with a relief of 18 m over 0.4 km. This is a moderately well drained soil of moderately slow to moderate permeability, formed in local alluvium overlying colluvium. The profile was wet when described.

Ap	0-20 cm	Dark brown (10YR 4/3) loam mixed with few fine distinct yellowish brown (10YR 5/8) mottles; moderate fine granular and weak fine subangular blocky structure; friable, nonsticky, nonplastic; many fine and medium roots; many very fine and fine, continuous random pores; slightly acid (6.2); abrupt smooth boundary.
Cg	20-50 cm	Gray (10YR 6/1) loam with common fine distinct strong brown (7.5YR 5/6) mottles; moderate to strong medium platy structure; friable, nonsticky, nonplastic; common medium roots; common, very fine discontinuous horizontal pores; medium acid (5.8); abrupt smooth boundary.
Apb	50-61 cm	Dark yellowish brown (10YR 4/4) loam; moderate coarse subangular blocky structure; friable, slightly sticky, slightly plastic; few roots; many, very fine, continuous, random and common fine continuous random pores; medium acid (5.8); abrupt wavy boundary.
B1b	61-86 cm	Yellowish brown (10YR 5/6) loam; moderate coarse subangular blocky structure; friable, slightly sticky, slightly plastic; few roots; many, very fine, continuous, random pores; common thin discontinuous argillans on ped faces; medium acid (5.8); clear wavy boundary.
IIB21b	86-109 cm	Strong brown (7.5YR 5/6) sandy clay loam with common medium fine reddish yellow (7.5YR 6/6) mottles; moderate medium subangular blocky structure; friabble, slightly sticky, slightly plastic; few roots; common, very fine, discontinuous, oblique and vertical pores; many, thin, continuous argillans on ped faces; medium acid (5.6); clear wavy boundary.
IIB22b	109-135 cm	Brown (7.5YR 5/4) clay loam and reddish brown (5YR 4/4) sandy clay loam banded material with common fine distinct strong brown (7.5YR 5/8) mottles; moderate medium subangular blocky and blocky structure; friable, slightly sticky, slightly plastic; few roots; common, very fine, discontinuous, oblique pores; many thick continuous argillans on ped faces; many, thin, discontinuous mangans on ped faces; medium acid (5.6); clear wavy boundary.

IIB23b 135-174 cm	Brown (7.5YR 5/4) clay loam with many coarse prominent pinkish gray (7.5YR 7/2) mottles; strong, medium and fine subangular blocky and blocky structure; firm, slightly sticky, plastic; few roots; few, very fine, discontinuous, oblique pores; many, thick, continuous argillans on ped faces and in pores; many, thick, continuous mangans on ped faces; medium acid (5.6); gradual wavy boundary.
IIIBxb 174-190 cm	Strong brown (7.5YR 5/6) sandy clay loam; moderate medium subangular blocky structure; firm, nonsticky, nonplastic; few roots; common, very fine, discontinuous, oblique pores; few, thin, discontinuous argillans on ped faces; common thin discontinuous mangans on ped faces; strongly acid (5.4).

Additional Notes:

1) Twenty four hours after the pit was excavated the effluent filled the pit to within 180 cm from the soil surface.

2) The site is at the foot of a 9% slope.

3) The pit intersected the clogging zone at a depth of approximately 90 centimenters from the soil surface.

Site 3

Described 9/15/80

This site occurs on a N facing concave slope of 5% under oak and white pine, at an elevation of 415 m with a relief of 30 m over .4 km. This is a well drained soil of moderate permeability. This soil has formed in residual dolomitic sandstone on the Gatesburg ridge in the "Pine Barrens". The profile was moist when described.

O1	4-1 cm	Black (10YR 2.5/1); oak leaf litter.
O2	1-0 cm	Black (10YR 2.5/1); decomposed litter.
A1	0-7 cm	Very dark grayish brown (10YR 3/2) and dark yellowish brown (10YR 4/4) coarse loamy sand; weak medium subangular blocky structure; very friable, nonsticky, nonplastic; many, coarse medium and fine roots; many, fine continuous oblique pores; strongly acid (5.4); abrupt wavy boundary.
A2	7-14 cm	Very pale brown (10YR 7/4) coarse loamy sand; weak medium subangular blocky structure; friable, nonsticky, nonplastic; many coarse and medium roots; many, very fine continuous oblique pores; medium acid (5.6); gradual wavy boundary.
A3	14-30 cm	Light yellowish brown (10YR 6/4) sandy loam; weak to moderate medium subangular blocky structure; friable, nonsticky, nonplastic; many medium roots; many, fine continuous oblique pores; medium acid (5.6); clear wavy boundary.
B11	30-44 cm	Yellowish brown (10YR 5/8) sandy loam; moderate medium subangular blocky structure; friable, nonsticky, nonplastic; many medium roots; many, very fine continuous vertical pores; medium acid (5.8); gradual wavy boundary.
B12	44-82 cm	Brownish yellow (10YR 6/8) sandy loam; moderate medium subangular blocky parting to weak medium platy structure; friable, nonsticky, nonplastic; few medium roots; many, very fine continuous oblique pores; few, thin discontinuous argillans in pores; few, thin discontinuous mangans on pedfaces; medium acid (5.6); clear wavy boundary.
B21	82-139 cm	Strong brown (7.5YR 5/8) sandy loam; strong very coarse prismatic parting to strong very coarse subangular blocky structure; very firm, nonsticky nonplastic; few medium roots; few, very fine discontinuous

horizontal pores; many, very thick continuous mangans on prismfaces; medium acid (5.8); clear wavy boundary.

B22t	139-162 cm	Brownish yellow (10YR 6/6) and yellowish brown (10YR 5/8) sandy clay loam, with reddish yellow (7.5YR 7/8) sand and yellowish red (5YR 5/8) loamy sand banding; moderate medium subangular blocky parting to strong medium platy structure; friable, nonsticky, slightly plastic; few roots; common, very fine discontinuous horizontal pores; common, thin discontinuous argillans on ped faces; common, thick continuous mangans on ped faces; medium acid (5.8); clear wavy boundary.
B31	162-217 cm	Strong brown (7.5YR 5/6) sandy clay loam, with reddish yellow (7.5YR 6/8) sand lenses; moderate coarse subangular blocky parting to strong medium platy structure; friable, nonsticky, slightly plastic; few roots; few, very fine discontinuous vertical pores; common, thick discontinuous argillans on ped faces; many, thin discontinuous mangans in pores and on ped faces; medium acid (6/0); clear wavy boundary.
B32	217-230 cm	Strong brown (7.5YR 5/6) and (7.5YR 5/8) coarse sandy loam; weak medium subangular blocky parting to moderate thin platy structure; very friable, nonsticky, nonplastic; few roots; common, very fine discontinuous random pores; common, thin discontinuous argillans on ped faces; many, thin discontinuous mangans in pores; medium acid (5.8).

Additional Notes:

1) Sand lenses in the B31 horizon were horizontal and discontinuous.

2) The brownish yellow (10YR 6/6) band in B22t was heavier in texture than the yellowish brown (10YR 5/8) band.

Site 4 Described 7/24/80

This site occurs on a NW facing convex slope of 6% at an elevation of 372 m and relief of 6 m over .4 km. This soil is deep, well drained, and of moderate permeability, with ground water deeper than 3 m. This soil was formed in local alluvial and colluvial material over residual limestone. The profile was moist when described.

Ap1	0-23 cm	Dark brown (10YR 3/3) silt loam with many medium distinct brownish yellow (10YR 6/8) and strong brown (7.5YR 5/6) clay loam inclusions; weak medium subangular blocky and moderate medium granular structure; friable, slightly sticky, nonplastic; many medium and fine roots; many, very fine continuous random pores; neutral (6.8); clear smooth boundary.
Ap2	23-35 cm	Dark brown (10YR 4/3) silt loam; moderate thin platy structure; friable, slightly sticky, nonplastic; many medium and fine roots; common, very fine continuous oblique and vertical pores; neutral (6.8), abrupt smooth boundary.
Ap3	35-66 cm	Dark brown (10YR 5/3) silt loam; weak medium prismatic parting to moderate coarse subangular blocky and moderate thick platy structure; friable, nonsticky, nonplastic; common medium roots; many, very fine continuous oblique horizontal and common, coarse continuous oblique pores; neutral (6.6); abrupt smooth boundary.
B1	66-86 cm	Brownish yellow (10YR 6/6) silt loam with many, fine distinct yellowish brown (10YR 5/6) mottles; moderate coarse subangular blocky structure; friable, nonsticky, slightly plastic; common medium roots; many, very fine continuous oblique and common, coarse continuous oblique pores; neutral (6.6); clear wavy boundary.
IIB21t	86-113 cm	Yellowish brown (10YR 5/8) silty clay loam with many fine faint brownish yellow (10YR 6/8) mottles; moderate medium subangular blocky structure; firm, slightly sticky, slightly plastic; few roots; few, very fine discontinuous oblique pores; common, thin discontinuous argillans on ped faces; common, thin continuous mangans on ped faces; medium acid (5.8); gradual wavy boundary.
IIB22t	113-140 cm	Yellowish brown (10YR 5/6) silty clay loam with common fine faint brownish yellow (10YR 6/8) and common medium prominent yellowish red (5YR 5/8) mottles; weak coarse prismatic parting to moderate medium

subangular blocky structure; firm, slightly sticky, plastic; few roots; common, very fine continuous oblique pores; common, thin discontinuous argillans on ped faces; common, thin discontinuous mangans on ped faces; medium acid (5.6); gradual wavy boundary.

IIB23t 140-163 cm — Yellowish red (5YR 5/8) silty clay loam; moderate coarse subangular blocky structure; firm, slightly sticky, plastic; no roots; many, very fine continuous vertical and oblique pores; common, thick continuous argillans on ped faces; common, thin discontinuous mangans on ped faces; many coarse prominent brownish yellow (10YR 6/8) mottles; medium acid (5.6); gradual wavy boundary.

IIB24t 163-192 cm — Strong brown (7.5YR 5/6) silty clay loam; weak medium prismatic parting moderate coarse subangular blocky structure; firm, sticky, plastic; common very fine, discontinuous, oblique pores; common, thick, continuous argillans on ped faces; common thin discontinuous mangans on ped faces; common medium distinct brownish yellow (10YR 6/6) mottles; medium acid (5.6); clear irregular boundary.

IIB3 192-245+ cm — Yellowish brown (10YR 5/6) silt loam and strong brown (7.5 YR 5/8) clay loam bands with many fine distinct brown (7.5YR 5/4) mottles; moderate and weak coarse subangular blocky; friable slightly sticky, slightly plastic; few very fine discontinuous vertical and common very fine discontinuous oblique pores; few, thin discontinuous argillans on ped faces; few, thin discontinuous mangans on ped faces; strong acid (5.4); clear wavy boundary.

Additional Notes:

1) IIB3 horizon is a mixture of two different materials with boundaries so irregular that a separation would be meaningless. The upper member is the darker silt loam material, roughly overlying the more clayey material. Clods were sampled from both materials (red and brown), the bulk sample was a mixture of both materials.

2) The mottles noted appear to be lithochromic, with duller colors overlying brighter ones; there appears to be no drainage problems. The presence of mangans suggests a naturally moist environment.

3) Ap designations were used to denote a plowed layer. Considerable deposition has occurred at this site resulting in a very thick Ap.

Site 5 Described 8/25/80

This site occurs on a SSW facing convex slope of 19% at an elevation of 335 m and relief of 49 m over .4 km. This soil is formed in shale colluvium over shale bedrock and is moderately well drained with ground water deeper than 1.8 m. This is the only soil of the 11 studied, which was described in the Appalachian Plateau.

Ap	0-20 cm	Pale brown (10YR 5/2) silt loam; medium strong granular and weak medium subangular blocky structure; friable, slightly sticky, nonplastic; many, fine and medium roots; many, medium continuous, oblique pores; slightly acid (6.4); abrupt smooth boundary.
A2	20-32 cm	Light yellowish brown (10YR 6/4) gravelly silt loam; weak fine platy and weak fine subangular blocky structure; friable, slightly sticky, nonplastic; many medium roots; many, very fine continuous horizontal and oblique pores; slightly acid (6.2); clear wavy boundary.
A3	32-50 cm	Light yellowish brown (10YR 6/4) very gravelly silt loam with common fine distinct, strong brown (7.5YR 5/8) mottles; weak coarse subangular blocky structure; friable to firm, slightly sticky, nonplastic; few roots; many, very fine continuous horizontal and oblique pores; medium acid (6.0); clear wavy boundary.
B21	50-94 cm	Yellowish brown (10YR 5/6) silty clay loam with many medium distinct yellowish red (5YR 5/6) mottles; weak medium prismatic and moderate medium subangular blocky structure; firm, slightly sticky, slightly plastic; few roots; many, very fine and fine continuous horizontal and oblique pores; common, thin discontinuous argillans on ped faces and common, thick continuous argillans in some pores; slightly acid (6.2); clear wavy boundary.
B22t	94-126 cm	Pale brown (10YR 6/3) silty clay loam with common medium prominent gray (10YR 6/1) and many coarse distinct yellowish red (5YR 5/6) mottles; moderate medium subangular blocky and weak fine prismatic structure; firm, slightly sticky, plastic; no roots; common, very fine and fine continuous horizontal and oblique pores; common, thin discontinuous argillans on ped faces, and continuous in pores; slightly acid (6.4); gradual wavy boundary.

B23t 126-155 cm Pale brown (10YR 6/3) silty clay loam with many medium prominent gray (10YR 6/1) and many common distinct yellowish red (5YR 5/6) mottles; moderate coarse subangular blocky structure; firm, slightly sticky, plastic; common, very fine and fine continuous oblique pores; many, thin continuous mangans in pores; slightly acid (6.4); clear wavy boundary.

IIC 155-175 cm Light yellowish brown (10YR 6/4) very shaly clay loam with few fine faint yellowish brown (10YR 5/6) mottles; moderate thin platy and moderate fine subangular blocky structure; friable sticky, slightly plastic; few, very fine discontinuous horizontal pores; many, thick discontinuous argillans on ped faces and in pores; medium acid (5.6).

Additional Notes:

1) The IIC horizon is interbedded shale; the less resistant shale has weathered to soil material.

2) The underlying rock exhibits a dip of 45°; and the rock fragments in the IIC horizon are dipped at 0°-10°.

Site 6 Described 9/13/80

This site occurs on a WNW facing convex slope of 5% under oak and maple vegetation at an elevation of 421 m and relief of 30 m over .4 km. This soil has formed in sandy dolomite residuum (on the Gatesburg ridge in the "Pine Barrens"), is well drained and moderately permeable. Ground water was deeper than the excavation, and the profile was moist when described.

O1	4-1 cm	Very dark grayish brown (10YR 3/2), oak and maple leaf litter.
O2	1-0 cm	Very dark grayish brown (10YR 3/2) decomposed litter.
A1	0-6 cm	Gray (10YR 6/1) loamy sand; moderate medium subangular blocky and moderate fine subangular blocky structure; friable, nonsticky, nonplastic; many medium and coarse roots; many, very fine continuous, oblique pores; very strongly acid (4.8); clear smooth boundary.
B2hir	6-11 cm	Light reddish brown (5YR 6/4) loamy sand with common medium distinct light brown (7.5YR 6/4) varigations; weak medium subangular blocky structure; friable, nonsticky, nonplastic; many medium and coarse roots; many, very fine continuous oblique pores; very strongly acid (5.0); abrupt wavy boundary.
A'2	11-19 cm	Very pale brown (10YR 8/4) loamy sand; weak fine subangular blocky structure; friable, nonsticky, nonplastic; many medium roots; many, very fine continuous random pores; medium acid (6.0); gradual wavy boundary.
A'3	19-41 cm	Brownish yellow (10YR 6/6) sandy loam; weak medium subangular blocky structure; friable, nonsticky, nonplastic; many medium roots; many, fine continuous random pores; medium acid (6.0); gradual wavy boundary.
B'21	41-55 cm	Yellowish brown (10YR 5/8) sandy clay loam with many fine faint brownish yellow (10YR 6/8) varigations; moderate medium subangular blocky structure; friable, slightly sticky, slightly plastic; many medium roots; many, fine continuous random pores; few, thin discontinuous argillans in pores; medium acid (5.8); clear wavy boundary.
B'22t	55-70 cm	Strong brown (7.5YR 5/8) sandy clay loam; moderate medium prismatic parting to moderate medium subangular

		blocky structure; friable, slightly sticky, slightly plastic; many medium roots; few, very fine continuous random pores; common, thin continuous argillans in pores; medium acid (5.6); gradual wavy boundary.
B'23t	70-91 cm	Reddish yellow (7.5YR 6/5) sandy clay loam; weak medium subangular blocky structure; friable, nonsticky, nonplastic; few fine roots; common, very fine discontinuous oblique pores; few, thin discontinuous argillans on ped faces; few, thick continuous mangans on some ped faces; medium acid (5.6); abrupt wavy boundary.
C1	91-124 cm	Brownish yellow (10YR 6/6) sandy loam with oblique bands of sand and horizontal bands of loamy sand with common medium distinct yellowish brown (10YR 5/4) and common coarse prominent white (10YR 8/2) varigations; weak medium subangular blocky and moderate medium prismatic structure in the sandy loam, and structureless single grain in the loamy sand; firm (in the sandy loam) and very friable (in the loamy sand), nonsticky, nonplastic; few fine roots; many, fine continuous random (in the sand band), and few, very fine discontinuous random pores; few, thin discontinuous argillans on ped faces; many, thick continuous mangans on ped faces; medium acid (5.6); clear wavy boundary.
C2	124-160 cm	Yellowish brown (10YR 5/8) loamy fine sand with many, coarse, distinct yellow (10YR 7/8), many coarse distinct reddish yellow (7.5YR 6/8), and common medium faint brownish yellow (10YR 6/8) varigations; structureless massive; friable, nonsticky, nonplastic; no roots; common, very fine discontinuous oblique pores; few, thin discontinuous argillans in pores; common, thick continuous mangans on coarse fragments; medium acid (5.6).

Additional Notes:

1) C1 horizon follows the strike of the bedrock left in the C2 horizon. The loamy sand lenses are discontinuous within the C1 horizon, one following the strike and terminating, the other overlying the bedrock and terminating in the control section. A layer of sandy clay loam lies between these lenses. This layer is varigated and heavily coated with manganese.

2) Depth to bedrock varies from 124 cm to the depth of the pit (160 cm).

Site 7

Described 8/28/80

This site occurs on a WSW facing convex slope of 4%, at an elevation of 378 m, and relief of 24 m over .4 km. The soil is well drained, with moderate permeability and deep ground water. The soil has formed in a tongue of old colluvium. The profile was moist when described.

Ap1	0-7 cm	Dark brown (10YR 4/3) silt loam; strong medium granular and moderate fine subangular blocky structure; very friable, nonsticky, nonplastic; neutral (6.6); abrupt smooth boundary.
Ap2	7-24 cm	Dark brown (10YR 3/3) silt loam; moderate thin platy structure; very friable, nonsticky, nonplastic; neutral (6.8); clear smooth boundary.
Ap3	24-37 cm	Dark brown (10YR 3/3) loam; moderate medium platy structure; friable, nonsticky, nonplastic; neutral (6.8); abrupt smooth boundary.
B21t	37-57 cm	Strong brown (7.5YR 5/6) clay loam; moderate medium subangular blocky structure; friable, slightly sticky, plastic; neutral (6.6); gradual wavy boundary.
B22t	57-86 cm	Yellowish red (5YR 5/6) clay; moderate medium subangular blocky and moderate medium prismatic structure; firm, slightly sticky, plastic; neutral (6.6); clear wavy boundary.
B23t	86-148 cm	Yellowish red (5YR 5/8) gravelly clay loam; moderate to strong medium prismatic structure; firm, nonsticky, slightly plastic; slightly acid (6.4); clear wavy boundary.
B24t	148-211 cm	Yellowish red (5YR 5/6) clay loam; moderate medium subangular blocky parting to moderate thin platy structure; firm; nonsticky, plastic; slightly acid (6.4); gradual wavy boundary.
B25	211-225 cm	Yellowish red (5YR 5/8) loam; weak medium subangular blocky parting to moderate thin platy structure; friable, nonsticky, nonplastic, slightly acid (6.2).

Site 8 Described 8/29/80

This site occurs on a SW facing concave slope of 2%, at an elevation of 372 m, with a relief of 12 m over .4 km. This soil was formed in alluvial/colluvial material overlying limestone residuum, has deep ground water, is moderately well drained, and moderate in permeability. The profile was moist when described.

Ap1	0-5 cm	Dark gray brown (10YR 4/2) silt loam, with common medium prominent pale brown (10YR 6/3) inclusions; moderate medium granular and weak fine subangular blocky structure; firm, nonsticky, nonplastic; neutral (6.6); abrupt smooth boundary.
Ap2	5-26 cm	Dark gray (10YR 4/1) silt loam, with few medium prominent yellowish red (5 YR 5/6) inclusions; moderate medium platy structure; firm, nonsticky, nonplastic; neutral (6.6); clear smooth boundary.
A2	26-40 cm	Dark gray brown (10YR 4/2) silt loam; moderate medium platy structure; firm, nonsticky, nonplastic; slightly acid (6.4); abrupt smooth boundary.
B21	40-54 cm	Pale brown (10YR 6/3) silt loam, with common medium faint brown (10YR 5/3) mottles; strong medium prismatic structure; firm, nonsticky, nonplastic; slightly acid (6.4); gradual wavy boundary.
B22t	54-80 cm	Dark yellowish brown (10YR 4/4) silty clay loam, with common fine distinct brownish yellow (10YR 6/6) mottles; moderate medium subangular blocky parting to strong fine blocky structure; firm, nonsticky, slightly plastic; slightly acid (6.4); gradual wavy boundary.
B23t	80-141 cm	Yellowish brown (10YR 5/4) silty clay loam; strong medium subangular blocky structure; firm, nonsticky, slightly plastic, slightly acid (6.4) abrupt broken boundary.
B31	141-172 cm	Yellowish brown (10YR 5/4) silt loam; moderate coarse subangular blocky structure; friable, nonsticky, nonplastic, slightly acid (6.4); abrupt irregular boundary.
B32g	172-185 cm	Gray (10YR 5/1) clay; moderate coarse subangular blocky structure; very firm, nonsticky, nonplastic; many, thick continuous argillans on ped faces; neutral (6.6).

Site 9 Described 7/30/80

This site occurs on a SW facing convex slope of 2% at an elevation of 409 m and a relief of 24 m over .4 km. The soil has formed in sandstone colluvium over calcareous shale residuum; is moderately well drained, moderately rapid in permeability, has deep ground water, and was moist when described.

Ap	0-10 cm	Dark brown (10YR 4/3) loam; moderate fine granular and weak fine subangular blocky structure; friable, slightly sticky, nonplastic; many fine roots; many, fine continuous random pores; slightly acid (6.4); abrupt smooth boundary.
A2	10-21 cm	Yellowish brown (10YR 5/6) loam with many medium prominent light gray (10YR 7/1) and few fine prominent reddish yellow (7.5YR 6/8) mottles; weak medium subangular blocky structure; very friable, nonsticky, nonplastic; many fine roots; many, fine continuous random and common, very fine discontinuous oblique pores; medium acid (6.0); abrupt smooth boundary.
B1	21-43 cm	Brownish yellow (10YR 6/6) loam; moderate medium platy parting to moderate medium subangular blocky structure; friable to firm, nonsticky, nonplastic; few fine roots; common, very fine discontinuous oblique pores; common, thin discontinuous argillans on ped faces; many, thin continuous mangans on ped faces; medium acid (5.8); clear wavy boundary.
B21t	43-65 cm	Yellowish red (5YR 5/6) sandy clay loam with common medium faint yellowish red (5YR 5/8) mottles; weak medium platy parting to strong fine blocky structure; very firm, nonsticky, slightly plastic; few fine roots; common, very fine discontinuous oblique pores; common, thin discontinuous argillans on ped faces; many, thin continuous mangans on ped faces; medium acid (5.6); clear wavy boundary.
B22t	65-122 cm	Yellowish red (5YR 5/6) sandy clay loam with a band of brown (7.5YR 5/4) loamy sand; moderate medium subangular blocky structure; very firm and friable (in band), slightly sticky and nonsticky (in band), slightly plastic and nonplastic (in band); few fine roots; common, very fine discontinuous oblique pores; many, thin continuous argillans on ped faces; many, thick continuous mangans on ped faces; medium acid (5.6); abrupt smooth boundary.

IIC1 122-135 cm Yellowish brown (10YR 5/6) silt loam with brownish yellow (10YR 6/8) and dark brown (10YR 4/3) bands; weak medium subangular blocky structure; very friable, nonsticky, nonplastic; few fine roots; few, very fine discontinuous oblique pores; strongly acid (5.4); abrupt smooth boundary.

IIC2 135-227 cm Yellowish brown (10YR 5/6) silty clay loam; weak coarse subangular blocky structure; friable, slightly sticky, plastic; no roots; many, fine continuous, oblique pores; many, thick discontinuous argillans on ped faces; medium acid (5.6).

Additional Notes:

1) On the west face of the pit a fragipan occurs at 35 to 65 cm and becomes shallower and thinner towards the control section where it disappears. This fragipan has moderate medium prismatic structure and gley mottles. On the east face of the pit the fragipan occurs at a depth of 65-95 cm from the soil surface.

2) The pit was dug to a depth of 227 cm, and soil samples were collected by augering in the bottom of the pit near the control section. The following is a description of the material found upon augering:

   a) 280 cm - strong brown (7.5YR 5/6) silty clay loam
   b) 290 cm - brownish yellow (10YR 6/8) clay loam
   c) 300 cm - gray and yellow sandy loam, many sandstone coarse fragments
   d) 320 cm - red and gray silty clay loam, few small coarse fragments
   e) 330 cm - red and yellow silty clay loam, coarse fragments of mixed lithologies
   f) 345 cm - red, yellow and gray heavy silty clay loam, coarse fragments of mixed lithologies
   g) 360 cm - red, yellow and gray light clay loam, coarse fragments of mixed lithologies (sandstone and calcareous shale)

3) IIC2 horizon was fractured calcareous shale rock with interces filled with the fine material described in the horizon.

Site 10

Described 7/18/80

This site occurs on a SSW facing convex slope of 3% at an elevation of 372 m and relief of 6 m over .4 km. This soil was formed in interlayered limestone residuums, is moderately well drained, moderately slow in permeability, and has deep ground water (greater than 2.7 m). The profile was moist when described.

A11 0-23 cm Dark brown (10YR 3/3) silt loam; weak medium subangular blocky parting to moderate fine granular structure; friable, nonsticky, nonplastic; many fine roots; many, fine continuous verticle pores; neutral (6.6); abrupt wavy boundary.

A12 23-38 cm Dark brown (7.5YR 4/2) silt loam; moderate medium platy structure; friable, slightly sticky, nonplastic; common fine roots; common, medium continuous oblique and common, fine continuous horizontal pores; neutral (6.6); clear wavy boundary.

A13 38-64 cm Dark brown (7.5YR 4/2) silt loam; moderate medium subangular blocky structure; friable, slightly sticky, nonplastic; common fine roots; many, fine and very fine continuous horizontal pores; slightly acid (6.4); abrupt wavy boundary.

B1 64-86 cm Brownish yellow (10YR 6/6) silt loam with many fine prominent strong brown (7.5YR 5/6) mottles and common medium distinct dark brown (10YR 4/3) illuviated silt; moderate coarse subangular blocky parting to moderate medium subangular blocky structure; friable, slightly sticky; nonplastic; few fine roots; many, fine continuous horizontal pores; few, thin discontinuous argillans on ped faces; medium acid (6.0); clear wavy boundary.

B21t 86-119 cm Strong brown (7.5YR 5/8) silty clay loam with many, medium, distinct dark brown (10YR 4/3) illuviated silts on ped faces; moderate medium subangular blocky structure; firm, slightly sticky, nonplastic; few fine roots; common, fine and very fine continuous random pores; common, thin discontinuous argillans on ped surfaces and in pores; common, thin continuous mangans on ped faces; medium acid (5.8); gradual wavy boundary.

B22t 119-152 cm Reddish yellow (7.5YR 6/6) silty clay loam with many, fine faint strong brown (7.5YR 5/6) mottles; weak medium prismatic parting to moderate coarse subangular

		blocky structure; firm, nonsticky, slightly plastic; few fine roots; common, very fine continuous random pores, many thin continuous mangans on ped faces; medium acid (5.6); gradual wavy boundary.
B23t	152-185 cm	Yellowish brown (10YR 5/6) silty clay loam with common medium faint strong brown (7.5YR 5/6) mottles; moderate coarse subangular blocky parting to moderate medium subangular blocky structure; firm, slightly sticky, slightly plastic; few fine roots; few, very fine discontinuous, oblique pores; many, thin discontinuous argillans on ped faces and in pores; many, thin discontinuous mangans on ped faces and in pores; strongly acid (5.4); clear wavy boundary.
B3	185-196 cm	Strong brown (7.5YR 5/6) clay loam and brownish yellow (10YR 6/6) silt loam bands 5 to 10 mm thick; moderate fine platy structure; friable, slightly sticky, plastic; few, very fine discontinuous horizontal pores; many, thick continuous argillans in pores; few, thin, discontinuous mangans on ped faces; strongly acid (5.4); clear smooth boundary.
IIC	196-246 cm	Very pale brown (10YR 7/4), light gray (10YR 7/2), and brownish yellow (10YR 6/6) bands of loamy fine sand and strong brown (7.5YR 5/6) clay streaks; weak coarse prismatic parting to weak fine platy structure; very friable, nonsticky, nonplastic; many, very fine continuous horizontal pores; common, thick continuous argillans in pores; many, thin continuous mangans on ped faces; medium acid (5.6).

Additional Notes:

1) The A horizons increase in thickness toward the NE end of the pit, ranging from less than 25 cm thick at the SW end to 100 cm thick at the NE end.

2) A ball of red (2.5YR 4/8) clay loam approximately 15 cm in diameter was observed in the ENE side of the pit.

Site 12 Described 7/9/80

This site occurs on an E facing convex slope of 1% at an elevation of 342 m and a relief of 12 m over .2 km. The soil is formed in made land-overlying lacustrine deposits on limestone residuum. The soil is well drained, moderately rapid in permeability, has ground water at 2.5 m, and was moist when described.

Ap	0-28 cm	Dark yellowish brown (10YR 4/4) silt loam; moderate medium subangular blocky and moderate fine granular structure; very friable, slightly sticky, slightly plastic; many fine roots; neutral (6.8); abrupt smooth boundary.
IIB21t	24-48 cm	Strong brown (7.5YR 5/6) silty clay loam; moderate medium prismatic parting to moderate medium subangular blocky structure; firm, slightly sticky, plastic; common fine roots; common, thin discontinuous argillans on ped faces; slightly acid (6.4); clear smooth boundary.
IIB22t	48-64 cm	Strong brown (7.5YR 5/8) silty clay with reddish yellow (7.5YR 6/6) silt loam bands 3 mm thick; moderate medium prismatic parting to moderate medium subangular blocky structure; firm, nonsticky, plastic; common fine roots; common, thin discontinuous argillans on ped faces; many, thin continuous mangans on ped faces; slightly acid (6.2); gradual wavy boundary.
IIB23t	64-86 cm	Strong brown (7.5YR 5/8) silty clay and reddish yellow silt loam bands as above; strong medium prismatic and strong coarse prismatic structure; firm, nonsticky, plastic; few fine roots; many, thin continuous argillans on ped faces; few, thin discontinuous mangans in ped interiors; slightly acid (6.2); gradual irregular boundary.
IIB24t	86-130 cm	Strong brown (7.5YR 5/8) silty clay with banding as above; strong very coarse prismatic structure; firm, nonsticky, plastic; few fine roots; many, thick continuous argillans on ped faces; many, thin discontinuous mangans on ped faces; slightly acid (6.2); gradual wavy boundary.
IIB25t	130-165 cm	Strong brown (7.5YR 5/8) silty clay with banding as above; strong very coarse prismatic structure; firm, nonsticky, plastic; no roots; many, thick continuous argillans on ped faces; many, thin discontinuous mangans on ped faces; medium acid (6.0); abrupt smooth boundary.

IIIAb 163-180 cm Grayish brown (10YR 5/2) silt loam with many medium distinct reddish yellow (7.5YR 6/8) mottles; weak medium subangular blocky structure; friable, slightly sticky, slightly plastic; many, thin continuous argillans on ped faces; common, thin discontinuous mangans on ped faces; near neutral (6.6); abrupt smooth boundary.

IIIBb 180-246 cm Brown (10YR 5/4) silt loam with common medium prominent gray (10YR 6/1) mottles; weak medium subangular blocky structure; friable, slightly sticky, slightly plastic; many, thin continuous argillans on ped faces; common, thick discontinuous mangans in pores; neutral (6.6).

Additional Notes:

1) Root channels extend to 64 cm, 3-5 mm wide, with organic material. Few extend to 90 cm. Large worm channels extend to about 125 cm with organic material.

2) A mixture of coal and iron slag occurs in the B21 horizon with small gravels of chert and other lithologies.

3) The Ap horizon was deposited by man as landscaping and was significantly drier than the rest of the profile. Some silty clay material appears as small inclusions.

4) The gross prismatic structural units were up to 125 cm in height and had horizontal planes of weakness, apparently due to the lacustrine deposition.

5) The water table was 2.5 m from the soil surface when the pit was dug. The next day the water table rose to a depth of 2 m from the soil surface.

6) Augering to 325 cm resulted in two underlying layers:

   a) 246-284 cm; dark brown silt loam with gray streaks; friable, slightly sticky, nonplastic.
   b) 284-325+ cm; dark brown clay; firm, slightly sticky, plastic; common fine distinct bright orange mottles.

APPENDIX E

Soil Characterization Data for the Eleven Sites Used in the Study

7701 SITE ONE LOAM

ROCK FRAGMENT DISTRIBUTION (WT) (PCT)

NO	DEPTH CM	HORIZON	> 76	76-19	19-4.7	4.7-2.0	TOTAL WT	TOTAL VOL	TEXTURAL CLASS LAB	TEXTURAL CLASS FIELD	TOTAL BULK DENSITY (G/CC)
1	0- 6	Ap		6.9	9.2	7.3	23.4		I	SIL	
2	6- 72	B21		26.2	7.4	1.3	35.0	23.4	L	L	1.53
3	72-107	B22		10.6	5.6	7.2	23.4	18.1	L	CL	1.61
4	107-122	A1L		56.5	0.8	0.4	57.7	40.8	SIL	SIL	1.48
5	122-142	A2b			2.2	2.8	5.0	2.8	SIL	L	1.51
6	142-158	B21b			3.0	1.7	4.7	3.3	L	CL	1.61
7	158-193	B22b									
8	193-216	B23b		0.9	4.8	4.4	10.1	8.2	L	CL	1.54
9	216-240	Cb		2.0	3.1	2.2	7.3	6.0	L	CL	1.51

PARTICLE SIZE DISTRIBUTION (MM) (PCT OF < 2 MM MATERIAL)

	SAND						SILT		TOTAL	TOTAL	TOTAL
NO	V COARSE 2.0-1.0	COARSE 1.0-0.5	MEDIUM 0.5-0.25	FINE 0.25-0.10	V FINE 0.10-0.07	V FINE 0.07-0.05	0.02-0.005	0.005-0.002	SAND 2.0-0.05	SILT 0.05-0.002	CLAY < 0.002
1	1.5	4.5	14.2	22.5	4.3	4.4	22.5	6.6	51.4	35.9	12.7
2	2.4	3.8	11.6	20.8	4.0	4.2	23.7	6.7	46.8	40.4	12.7
3	1.0	2.9	8.7	16.9	4.1	0.1	35.1	6.7	33.6	44.5	21.8
4	1.4	2.6	6.5	13.2	3.2	4.1	36.3	10.2	31.0	54.1	14.9
5	0.8	2.0	6.5	13.1	3.4	3.8	35.4	10.8	29.6	54.7	15.8
6	2.1	2.8	7.0	14.5	3.6	4.8	25.0	8.3	34.8	40.5	24.7
7											
8	1.3	2.3	4.9	11.5	4.4	0.1	42.5	9.7	24.5	49.0	26.5
9	1.8	2.5	8.3	18.4	6.6	7.2	21.7	7.7	44.9	38.1	17.0

	BULK DENSITY (G/CG) 1/3 ATM MOISTURE		DRY		MOISTURE (PCT) RETAINED AT 1/3 ATM		15 ATM	AVAILABLE MOISTURE < 2 MM MATERIAL		TOTAL SOIL (< 2 MM + FRAGMENTS)	
NO	ENTIRE CLOD	< 2 MM IN CLOD	< 2 MM IN CLOD	COLE < 2 MM CLOD	ENTIRE < 2 MM IN CLOD	< 2 MM SIEVED		WEIGHT (PCT)	CM/CM OF SOIL	WEIGHT (PCT)	CM/CM OF SOIL
1											
2	1.41	1.33	1.39	0.008	19.1	23.4	6.8				
3	1.58	1.52	1.86	0.086	13.5	16.1	6.4	17.0	0.226	17.0	0.220
4	1.06	1.06	1.10	0.011	28.5	28.6	8.0	8.1	0.123	8.1	0.122
5	1.47	1.47	1.54	0.014	17.5	17.5	13.8	14.8	0.157	14.8	0.157
6	1.62	1.59	1.67	0.016	18.3	19.4	6.0	11.5	0.169	11.5	0.169
7							9.3	10.1	0.161	10.1	0.159
8	1.52	1.51	1.55	0.009	18.1	19.0	8.3	10.7	0.162	10.7	0.161
9	1.50	1.49	1.51	0.005	16.1	17.1	5.9	11.2	0.167	10.3	0.166

7702 SITE TWO LOAM

ROCK FRAGMENT DISTRIBUTION (MM) (PCT)

NO	DEPTH CM	HORIZON	> 76	76-19	19-4.7	4.7-2.0	TOTAL WT	TOTAL VOL	TEXTURAL CLASS LAB	TEXTURAL CLASS FIELD	TOTAL BULK DENSITY (G/CC)
1	0- 20	Ap		14.8	9.1	11.3	35.2	30.9	L	L	1.79
2	20- 50	Cg		22.6	5.6	3.5	31.7	23.7	L	L	1.77
3	50- 61	Apb		35.1	12.9	1.1	49.0	36.2	L	L	1.86
4	61- 86	B1b		7.7	9.6	2.8	20.2	14.9	L	L	1.75
5	86-109	IIB21b		28.9	6.8	4.6	40.3	33.4	L	SCL	1.90
6	109-135	IIB22b		21.8	9.4	4.8	36.0	30.1	L	CL	1.90
7	135-174	IIB23b		2.8	1.7	0.3	4.7	3.7	CL	CL	1.60
8	174-190	IIIBxb		47.7	12.6	3.5	63.8	56.2	FSL	SCL	2.15

PARTICLE SIZE DISTRIBUTION (MM) (PCT OF < 2 MM MATERIAL)

NO	SAND V COARSE 2.0-1.0	SAND COARSE 1.0-0.5	SAND MEDIUM 0.5-0.25	SAND FINE 0.25-0.10	SAND V FINE 0.10-0.07	SAND V FINE 0.07-0.05	SILT 0.02-0.005	SILT 0.005-0.002	TOTAL SAND 2.0-0.05	TOTAL SILT 0.05-0.002	TOTAL CLAY < 0.002
1	1.6	3.4	9.3	17.2	4.4	3.2	24.8	9.4	39.1	42.7	18.2
2	1.9	3.2	10.9	19.0	4.6		28.6	8.9	39.6	43.1	17.2
3	2.3	3.0	10.8	20.0	4.7	4.6	29.2	9.1	45.4	42.2	12.4
4	1.0	2.1	9.4	18.4	4.4	3.7	31.5	9.3	39.0	42.3	18.7
5	2.3	3.3	12.2	20.0	5.0	4.5	16.4	7.7	47.2	33.8	19.0
6	2.4	3.6	11.0	18.6	5.2	4.6	21.0	7.6	45.4	29.9	24.7
7	1.8	1.9	4.9	7.5	2.2	3.3	35.3	11.9	21.6	39.4	39.0
8	3.6	5.5	14.1	24.2	6.0	5.8	16.4	6.5	59.2	26.8	14.0

NO	BULK DENSITY (G/CG) 1/3 ATM MOISTURE ENTIRE CLOD	1/3 ATM MOISTURE < 2 MM IN CLOD	DRY < 2 MM IN CLOD	COLE	MOISTURE (PCT) RETAINED AT 1/3 ATM ENTIRE < 2 MM CLOD	1/3 ATM < 2 MM IN CLOD	15 ATM < 2 MM SIEVED	AVAILABLE MOISTURE < 2 MM MATERIAL WEIGHT (PCT)	AVAILABLE MOISTURE < 2 MM MATERIAL CM/CM OF SOIL	TOTAL SOIL (< 2 MM + FRAGMENTS) WEIGHT (PCT)	TOTAL SOIL (< 2 MM + FRAGMENTS) CM/CM OF SOIL
1	1.69	1.68	1.71	0.006	16.4	17.7	8.6	9.1	0.153	5.9	0.152
2	1.67	1.59	1.62	0.008	16.1	18.5	8.7	9.8	0.156	9.9	0.157
3	1.68	1.49	1.56	0.013	11.9	17.6	6.6	11.0	0.164	11.0	0.157
4	1.69	1.64	1.69	0.009	15.6	17.0	6.2	10.8	0.177	10.8	0.178
5	1.75	1.70	1.77	0.013	15.7	18.0	7.7	10.3	0.175	10.3	0.175
6	1.81	1.74	1.85	0.021	13.1	15.9	11.6	4.3	0.075	4.4	0.075
7	1.60	1.59	1.77	0.039	20.7	21.3	16.8	4.5	0.072	5.0	0.069
8	1.85	1.77	1.86	0.017	10.9	13.2	6.5	6.7	0.119	6.7	0.117

7703 SITE THREE LOAMY SAND

ROCK FRAGMENT DISTRIBUTION (MM) (PCT)

NO	DEPTH CM	HORIZON	> 76	76-19	19-4.7	4.7-2.0	TOTAL WT	TOTAL VOL	TEXTURAL CLASS LAB	TEXTURAL CLASS FIELD	TOTAL BULK DENSITY (G/CC)
1	0- 7	A1			0.5	1.5	2.0		LS	CLS	
2	7- 14	A2		0.6	2.3	0.9	3.8		LS	CLS	
3	14- 30	A3		3.3	6.2	2.5	11.9	9.7	SL	SL	1.64
4	30- 44	B11		0.3	2.9	2.7	5.8	3.6	SL	SL	1.65
5	44- 82	B12		2.9	5.6	2.3	10.9	8.0	SL	SL	1.79
6	82-139	B21			1.4	0.4	1.7	1.2	SCL	SL	1.87
7	139-162	B22t		1.3	2.3	0.3	3.9	1.9	SCL	SCL	
8	162-217	B31		5.6	1.1	0.2	6.9	9.4	SCL	SCL	
9	217-230	B32	25.8	5.0	3.4	1.2	35.4		SCL	CSL	

PARTICLE SIZE DISTRIBUTION (MM) (PCT OF < 2 MM MATERIAL)

	SAND						SILT		TOTAL	TOTAL	TOTAL
	V COARSE	COARSE	MEDIUM	FINE	V FINE				SAND	SILT	CLAY
	2.0-	1.0-	0.5-	0.25-	0.10-	0.07-	0.02-	0.005-	2.0-	0.05-	<
NO	1.0	0.5	0.25	0.10	0.07	0.05	0.005	0.002	0.05	0.002	0.002
1	0.4	8.7	38.8	25.3	2.5	2.0	11.7	3.0	77.8	17.3	4.9
2	0.4	9.8	39.2	25.1	2.6	1.3	11.5	2.7	78.5	19.2	2.3
3	0.7	8.5	33.7	20.9	2.0	1.7	17.1	4.6	67.5	26.1	6.4
4	0.9	8.9	32.9	18.9	1.6	1.5	13.9	2.7	64.7	20.6	14.7
5	0.3	7.8	30.7	23.3	3.3	2.2	13.4	3.8	67.5	20.5	12.0
6	0.2	7.5	36.8	21.5	2.6	1.3	3.0	1.6	69.9	5.1	25.1
7	0.1	4.9	27.1	23.7	2.5	1.4	10.4	3.9	59.8	14.2	26.0
8	0.4	5.0	25.2	25.9	3.4	3.3	6.0	3.1	63.2	11.0	25.8
9	0.3	5.2	27.1	27.6	3.2	3.2	6.0	2.3	66.7	11.2	22.1

	BULK DENSITY (G/CG) 1/3 ATM MOISTURE		DRY		MOISTURE (PCT) RETAINED AT 1/3 ATM		15 ATM	AVAILABLE MOISTURE < 2 MM MATERIAL		TOTAL SOIL (< 2 MM + FRAGMENTS)	
	ENTIRE	< 2 MM	< 2 MM	COLE	ENTIRE	< 2 MM	< 2 MM	WEIGHT	CM/CM	WEIGHT	CM/CM
NO	CLOD	IN CLOD	IN CLOD	< 2 MM	CLOD	IN CLOD	SIEVED	(PCT)	OF SOIL	(PCT)	OF SOIL
1							5.9				
2							1.8				
3	1.62	1.59	1.67	0.016	9.3	10.2	2.8	7.4	0.118	6.5	0.107
4	1.62	1.62	1.62	0.005	11.7	11.7	5.9	5.8	0.094	5.8	0.094
5	1.79	1.73	1.77	0.006	10.1	11.3	4.6	6.7	0.116	6.7	0.116
6	1.86	1.86	1.95	0.014	10.8	10.8	8.1	2.7	0.050	2.7	0.049
7	1.83		1.91		10.9		7.8				
8	1.41		1.88		11.3		8.3				
9							7.6				

7704 SITE FOUR SILTY CLAY LOAM

ROCK FRAGMENT DISTRIBUTION (MM) (PCT)

NO	DEPTH CM	HORIZON	> 76	76-19	19-4.7	4.7-2.0	TOTAL WT	TOTAL VOL	TEXTURAL CLASS LAB	TEXTURAL CLASS FIELD	TOTAL BULK DENSITY (G/CC)
1	0- 23	Ap1			8.5	3.5	12.0	8.1	SICL	SIL	1.45
2	23- 35	Ap2			2.9	7.0	9.9	6.0	SIL	SIL	1.47
3	35- 66	Ap3			6.8	1.9	8.8	5.0	SIL	SIL	1.32
4	66- 86	B1			8.2	5.1	13.3		SICL	SIL	
5	86-113	IIB21t			2.0	0.8	2.8	1.8	SIC	SICL	1.52
6	113-140	IIB22t			4.9	3.8	8.7	6.0	SIC	SICL	1.59
7	140-163	IIB23t			4.3	1.3	5.7	2.8	C	SICL	1.07
8	163-192	IIB24t			6.3	1.0	7.3	5.0	SIC	SICL	1.56
9	192-245	IIB3			13.7	3.5	17.3	12.2	SICL	SIL	1.58

PARTICLE SIZE DISTRIBUTION (MM) (PCT OF < 2 MM MATERIAL)

	SAND						SILT		TOTAL	TOTAL	TOTAL
	V COARSE	COARSE	MEDIUM	FINE	V FINE				SAND	SILT	CLAY
	2.0-	1.0-	0.5-	0.25-	0.10-	0.07-	0.02-	0.005-	2.0-	0.05-	<
NO	1.0	0.5	0.25	0.10	0.07	0.05	0.005	0.002	0.05	0.002	0.002
1	1.6	2.4	2.5	2.3	0.8	1.7	44.9	13.5	11.3	60.1	28.6
2	1.6	2.1	1.9	1.8	0.8	1.4	49.7	14.2	9.6	67.4	22.9
3	1.1	2.7	2.4	2.0	0.7	1.4	41.7	14.2	10.3	68.6	21.1
4	0.8	2.3	2.1	1.9	0.7	1.4	46.8	14.9	9.1	61.0	29.8
5	1.1	0.7	0.7	0.9	0.6	1.1	31.7	11.7	5.1	40.1	54.7
6	1.1	1.6	1.4	1.4	0.7	1.3	38.9	11.7	7.4	49.4	43.2
7	0.2	0.5	0.6	0.7	0.4	0.7	32.4	10.5	3.2	39.8	57.0
8	0.5	0.8	0.7	0.8	0.4	0.9	26.3	10.3	4.1	41.5	54.5
9	2.0	1.9	1.9	1.9	0.7	1.6	36.2	11.6	10.0	51.1	38.9

	BULK DENSITY (G/CG) 1/3 ATM MOISTURE		DRY		MOISTURE (PCT) RETAINED AT 1/3 ATM		15 ATM	AVAILABLE MOISTURE < 2 MM MATERIAL		TOTAL SOIL (< 2 MM + FRAGMENTS)	
NO	ENTIRE CLOD	< 2 MM IN CLOD	< 2 MM IN CLOD	COLE < 2 MM CLOD	ENTIRE < 2 MM CLOD	< 2 MM IN CLOD	< 2 MM SIEVED	WEIGHT (PCT)	CM/CM OF SOIL	WEIGHT (PCT)	CM/CM OF SOIL
1	1.45	1.39	1.46	0.019	21.1	23.9	14.9	9.0	0.125	8.9	0.124
2	1.45	1.41	1.47	0.016	24.1	25.8	9.3	16.5	0.233	16.5	0.232
3	1.32	1.27	1.31	0.010	25.7	28.0	9.3	18.7	0.237	18.7	0.238
4							11.3				
5	1.51	1.50	1.64	0.030	24.1	24.6	17.9	6.7	0.101	6.7	0.101
6	1.57	1.54	1.64	0.020	20.3	21.5	14.0	7.5	0.115	7.4	0.114
7	1.07	1.03	1.60	0.158	22.6	24.2	16.9	7.3	0.075	7.4	0.076
8	1.53	1.52	1.66	0.030	22.8	22.9	16.6	6.3	0.096	6.3	0.096
9	1.52	1.49	1.58	0.020	20.1	21.5	12.5	9.0	0.134	9.0	0.134

7705 SITE FIVE SILT LOAM

ROCK FRAGMENT DISTRIBUTION (MM) (PCT)

NO	DEPTH CM	HORIZON	> 76	76-19	19-4.7	4.7-2.0	TOTAL WT	TOTAL VOL	TEXTURAL CLASS LAB	TEXTURAL CLASS FIELD	TOTAL BULK DENSITY (G/CC)
1	0- 20	Ap		16.0	29.3	10.5	55.8		SIL	SIL	
2	20- 32	A2		22.4	25.6	8.4	56.4	40.7	SIL	SIL	1.79
3	32- 50	A3		11.8	28.9	13.3	54.0	43.4	SIL	SIL	1.90
4	50- 94	B21		16.9	14.4	8.6	39.9	32.2	SICL	SICL	1.88
5	94-126	B22t		28.5	15.3	12.5	56.3	46.1	SICL	SICL	2.08
6	126-155	B23t		8.1	15.1	9.8	33.0	29.4	SICL	SICL	
7	155-175	IIC		23.5	22.1	14.5	60.0		SICL	VGCL	

PARTICLE SIZE DISTRIBUTION (MM) (PCT OF < 2 MM MATERIAL)

	SAND						SILT		TOTAL	TOTAL	TOTAL
	V COARSE	COARSE	MEDIUM	FINE	V FINE				SAND	SILT	CLAY
	2.0-	1.0-	0.5-	0.25-	0.10-	0.07-	0.02-	0.005-	2.0-	0.05-	<
NO	1.0	0.5	0.25	0.10	0.07	0.05	0.005	0.002	0.05	0.002	0.002
1	5.6	3.6	1.2	1.1	0.6	1.3	52.0	16.1	13.5	65.8	20.7
2	5.9	3.1	1.0	0.7	0.4	1.0	54.2	18.9	12.1	66.8	21.2
3	10.3	5.8	2.1	1.5	0.6	1.3	48.5	14.6	21.6	59.1	19.3
4	2.3	2.7	2.0	2.3	1.0	1.3	49.7	16.7	11.6	58.0	30.4
5	2.5	3.8	2.3	2.3	1.0	1.1	49.2	16.0	13.1	57.5	29.4
6	2.2	3.3	3.0	3.5	1.2	1.4	48.4	18.4	14.6	54.2	31.2
7	2.7	3.6	3.8	3.8	1.3	1.3	48.8	19.4	16.3	54.2	29.4

	BULK DENSITY (G/CG) 1/3 ATM MOISTURE		DRY		MOISTURE (PCT) RETAINED AT			AVAILABLE MOISTURE < 2 MM MATERIAL		TOTAL SOIL (< 2 MM + FRAGMENTS)	
					1/3 ATM		15 ATM				
NO	ENTIRE CLOD	< 2 MM IN CLOD	< 2 MM IN CLOD	COLE < 2 MM	ENTIRE CLOD	< 2 MM IN CLOD	< 2 MM SIEVED	WEIGHT (PCT)	CM/CM OF SOIL	WEIGHT (PCT)	CM/CM OF SOIL
1							8.8				
2	1.61	1.31	1.41	0.023	16.5	27.1	8.3	18.8	0.246	18.8	0.247
3	1.81	1.55	1.58	0.006	13.7	23.9	7.2	16.7	0.259	16.7	0.258
4	1.75	1.66	1.77	0.022	16.0	19.4	12.0	7.4	0.123	7.4	0.121
5	1.81	1.69	1.78	0.018	15.0	17.4	10.7	6.7	0.113	6.7	0.113
6	1.84	1.96	1.96	0.021	14.3	21.2	11.2	10.0	0.196	3.3	0.065
7							10.5				

7706 SITE SIX LOAMY SAND

ROCK FRAGMENT DISTRIBUTION (MM) (PCT)

NO	DEPTH CM	HORI-ZON	> 76	76-19	19-4.7	4.7-2.0	TOTAL WT	TOTAL VOL	TEXTURAL CLASS LAB	TEXTURAL CLASS FIELD	TOTAL BULK DENSITY (G/CC)
1	0- 6	A1			0.4	0.9	1.3		LS	LS	
2	6- 11	B2hir			0.4	0.9	1.3		LS	LS	
3	11- 19	A'2		2.3	2.7	1.0	6.0		LS	LS	
4	19- 41	A'3		20.2	5.0	0.6	25.8	19.4	SL	SL	1.69
5	41- 55	B'21		6.6	2.3	1.1	9.9	5.2	SL	SCL	1.28
6	55- 70	B'22t		0.2	0.8	1.8	2.8	2.4	SCL	SCL	
7	70- 91	B'23t		4.7	4.3	3.6	12.6	9.1	LS	SCL	1.99
8	91-124	C1		2.1	5.5	3.2	10.7	8.2	SL	SL	1.78
9	124-160	C2	55.4	24.2	1.0	0.4	81.1		FSL	LFS	

PARTICLE SIZE DISTRIBUTION (MM) (PCT OF < 2 MM MATERIAL)

	SAND						SILT		TOTAL	TOTAL	TOTAL
NO	V COARSE 2.0-1.0	COARSE 1.0-0.5	MEDIUM 0.5-0.25	FINE 0.25-0.10	V FINE 0.10-0.07	V FINE 0.07-0.05	0.02-0.005	0.005-0.002	SAND 2.0-0.05	SILT 0.05-0.002	CLAY < 0.002
1	3.7	8.6	37.4	31.2	2.4	2.1	9.7	3.6	85.4	11.3	3.2
2	0.1	8.7	38.1	30.4	3.1	2.2	8.0	2.3	82.5	13.2	4.3
3	0.3	7.9	36.3	29.7	2.2	1.8	10.1	2.1	78.1	15.6	6.4
4	0.3	8.1	34.2	27.0	2.7		12.2	7.1	72.4	19.7	7.9
5	0.3	6.3	31.0	26.6	2.4	1.7	10.5	5.8	68.3	15.7	16.0
6	0.4	7.9	35.6	23.6	2.9	1.2	7.4	3.3	71.5	7.8	20.6
7	0.7	7.2	33.2	35.0	4.7	2.9	4.1	1.2	83.7	7.1	9.1
8	0.9	5.6	26.5	22.7	6.3	3.7	10.4	4.5	65.6	16.6	17.8
9	0.7	2.1	23.2	52.5	1.9	1.2	2.4	1.6	81.7	4.9	13.4

	BULK DENSITY (G/CG) 1/3 ATM MOISTURE		DRY		MOISTURE (PCT) RETAINED AT 1/3 ATM		15 ATM	AVAILABLE MOISTURE < 2 MM MATERIAL		TOTAL SOIL (< 2 MM + FRAGMENTS)	
NO	ENTIRE CLOD	< 2 MM IN CLOD	< 2 MM IN CLOD	COLE < 2 MM CLOD	ENTIRE CLOD	< 2 MM IN CLOD	< 2 MM SIEVED	WEIGHT (PCT)	CM/CM OF SOIL	WEIGHT (PCT)	CM/CM OF SOIL
1							5.5				
2							2.6				
3							2.6				
4	1.51	1.50	1.62	0.029	9.4	9.8	4.0	5.8	0.087	4.3	0.073
5	1.16	1.15	1.57	0.110	9.9	10.3	6.3	4.0	0.046	3.5	0.045
6	1.65		1.69		11.7		7.1				
7	1.84	1.82	1.83	0.002	5.0	5.2	3.2	2.0	0.036	2.0	0.037
8	1.81	1.74	1.75	0.002	8.5	10.0	6.6	3.4	0.059	3.5	0.060
9							4.7				

7707 SITE SEVEN LOAM

ROCK FRAGMENT DISTRIBUTION (MM) (PCT)

NO	DEPTH CM	HORIZON	> 76	76-19	19-4.7	4.7-2.0	TOTAL WT	TOTAL VOL	TEXTURAL CLASS LAB	TEXTURAL CLASS FIELD	TOTAL BULK DENSITY (G/CC)
1	0- 7	Ap1									
2	7- 24	Ap2			12.0	5.3	17.3		L	SCL	
3	24- 37	Ap3			10.7	6.1	16.7		L	SIL	
4	37- 57	B21t			7.6	2.2	9.8	6.3	L	L	1.64
5	57- 86	B22t			9.4	2.1	11.5	8.3	L	CL	1.67
6	86-148	B23t			3.4	3.9	7.4	5.3	CL	C	1.59
7	148-211	B24t			16.4	1.8	18.2	12.0	CL	CL	1.63
8	211-225	B25			11.9	3.1	14.9	9.2	CL	CL	1.61
					12.7	7.9	20.6	14.4	SCL	L	1.68

PARTICLE SIZE DISTRIBUTION (MM) (PCT OF < 2 MM MATERIAL)

NO	SAND V COARSE 2.0-1.0	SAND COARSE 1.0-0.5	SAND MEDIUM 0.5-0.25	SAND FINE 0.25-0.10	SAND V FINE 0.10-0.07	SAND V FINE 0.07-0.05	SILT 0.02-0.005	SILT 0.005-0.002	TOTAL SAND 2.0-0.05	TOTAL SILT 0.05-0.002	TOTAL CLAY < 0.002
1	2.2	3.4	11.8	13.6	3.2	2.9	30.7	7.3	37.1	46.1	16.8
2	2.4	3.7	12.5	12.5	3.4	2.6	33.6	8.0	37.1	46.6	16.3
3	4.6	4.1	12.2	12.2	3.1	2.5	30.4	7.0	38.7	43.5	17.8
4	3.7	4.6	12.6	11.5	2.2	2.1	24.6	6.3	36.5	36.9	26.5
5	2.1	2.5	7.6	8.8	2.6	2.4	26.5	7.2	25.8	38.3	35.9
6	3.7	5.6	14.5	13.4	3.1	2.5	15.3	5.6	42.8	21.4	35.9
7	3.6	5.4	14.9	14.1	3.1	2.6	17.9	5.1	43.8	27.8	28.4
8	2.5	5.0	15.8	17.1	5.3	3.8	13.9	3.3	49.6	24.4	26.0

NO	BULK DENSITY (G/CG) 1/3 ATM MOISTURE ENTIRE CLOD	1/3 ATM MOISTURE < 2 MM IN CLOD	DRY < 2 MM IN CLOD	COLE < 2 MM CLOD	MOISTURE (PCT) RETAINED AT 1/3 ATM ENTIRE < 2 MM IN CLOD	1/3 ATM < 2 MM SIEVED	15 ATM	AVAILABLE MOISTURE < 2 MM MATERIAL WEIGHT (PCT)	CM/CM OF SOIL	TOTAL SOIL (< 2 MM + FRAGMENTS) WEIGHT (PCT)	CM/CM OF SOIL
1											
2							4.7				
3	1.62	1.58	1.68	0.020	16.5	17.7	8.4				
4	1.70	1.61	1.75	0.029	15.6	19.7	7.9	9.8	0.155	9.8	0.155
5	1.59	1.56	1.73	0.035	19.0	20.1	10.5	9.2	0.148	9.1	0.146
6	1.68	1.51	1.59	0.018	16.1	21.6	13.7	6.4	0.100	6.4	0.100
7	1.70	1.51	1.64	0.029	14.4	19.8	12.5	9.1	0.137	9.1	0.157
8	1.69	1.56	1.75	0.039	14.0	17.8	10.3	9.5	0.143	9.5	0.143
							10.0	7.8	0.122	7.8	0.121

7708 SITE EIGHT SILTY CLAY LOAM

ROCK FRAGMENT DISTRIBUTION (MM) (PCT)

NO	DEPTH CM	HORIZON	> 76	76-19	19-4.7	4.7-2.0	TOTAL WT	TOTAL VOL	TEXTURAL CLASS LAB	TEXTURAL CLASS FIELD	TOTAL BULK DENSITY (G/CC)
1	0- 5	Ap1			1.3	0.5	1.7		SICL	SIL	
2	5- 26	Ap2			1.5	1.5	3.0	1.5	SIL	SIL	1.03
3	26- 40	A2			0.6	0.5	1.2	0.6	SICL	SIL	1.34
4	40- 54	B21			4.0	4.9	8.9	5.8	SICL	SIL	1.54
5	54- 80	B22t			9.0	35.5	44.5	37.1	SIC	SICL	1.63
6	80-141	B23t			4.2	13.8	18.0		SICL	SICL	
7	141-172	B31			8.8	13.7	22.5	15.2	SICL	SIL	1.59
8	172-185	B32g				1.4	1.4	0.8	SIC	C	1.29

PARTICLE SIZE DISTRIBUTION (MM) (PCT OF < 2 MM MATERIAL)

	SAND						SILT		TOTAL	TOTAL	TOTAL
	V COARSE	COARSE	MEDIUM	FINE	V FINE				SAND	SILT	CLAY
NO	2.0-1.0	1.0-0.5	0.5-0.25	0.25-0.10	0.10-0.07	0.07-0.05	0.02-0.005	0.005-0.002	2.0-0.05	0.05-0.002	< 0.002
1	0.6	0.8	3.1	3.9	1.3	1.2	46.5	12.2	11.0	58.2	30.9
2	0.7	1.0	2.2	2.6	1.1	1.3	51.9	13.2	8.9	66.1	25.0
3	0.5	0.6	2.2	3.9	2.0	1.6	44.4	12.5	10.9	61.9	27.2
4	0.6	0.8	2.0	3.6	1.9	1.5	37.4	12.1	10.3	51.0	36.6
5	1.7	1.5	1.7	2.1	1.2	1.4	35.3	9.8	9.7	49.8	40.5
6	1.0	1.0	1.0	1.5	1.0	1.5	43.3	11.1	6.8	60.9	32.2
7	1.9	1.8	1.6	2.0	1.2	1.5	42.7	10.6	10.1	60.7	29.2
8		0.1	0.5	1.9	1.7	2.2	37.0	9.3	6.4	49.4	44.3

	BULK DENSITY (G/CC) 1/3 ATM MOISTURE		BULK DENSITY (G/CC) DRY		MOISTURE (PCT) RETAINED AT 1/3 ATM		MOISTURE (PCT) RETAINED AT 15 ATM	AVAILABLE MOISTURE < 2 MM MATERIAL		AVAILABLE MOISTURE TOTAL SOIL (< 2 MM + FRAGMENTS)	
NO	ENTIRE CLOD	< 2 MM IN CLOD	< 2 MM IN CLOD	COLE < 2 MM CLOD	ENTIRE CLOD	< 2 MM IN CLOD	< 2 MM SIEVED	WEIGHT (PCT)	CM/CM OF SOIL	WEIGHT (PCT)	CM/CM OF SOIL
1							18.6				
2	1.02	1.02	1.41	0.114	29.5	29.7	17.3	12.4	0.126	12.4	0.126
3	1.43	1.34	1.39	0.013	24.3	20.3	18.4	1.9	0.025	1.9	0.025
4	1.51	1.49	1.86	0.076	23.4	24.0	16.9	7.1	0.106	7.1	0.105
5	1.46	1.44	1.80	0.076	23.6	25.3	16.9	8.4	0.121	8.4	0.121
6							14.5				
7	1.53	1.46	1.64	0.040	18.1	20.7	12.8	7.9	0.115	7.9	0.116
8	1.29	1.29	1.46	0.131	16.2	16.2	14.1	2.1	0.027	2.1	0.027

7709 SITE NINE SILT LOAM

ROCK FRAGMENT DISTRIBUTION (MM) (PCT)

NO	DEPTH CM	HORIZON	> 76	76-19	19-4.7	4.7-2.0	TOTAL WT	TOTAL VOL	TEXTURAL CLASS LAB	TEXTURAL CLASS FIELD	TOTAL BULK DENSITY (G/CC)
1	0- 10	Ap		1.9	4.1	12.8	18.8	10.0	SIL	L	1.26
2	10- 21	A2		32.7	1.9	1.9	36.5	21.4	SIL	L	1.41
3	21- 43	B1		15.8	5.8	5.2	26.8	14.0	L	L	1.46
4	43- 65	B21t		22.5	4.6	3.1	30.2	19.5	CL	SICL	1.53
5	65-122	B22t		18.3	6.3	6.4	31.0	23.9	CL	SCL	1.89
6	122-135	IIC1			0.3	6.9	7.2	4.4	CL	SIL	1.61
7	135-227	IIC2		33.1	9.5	5.1	47.7		L	SICL	

PARTICLE SIZE DISTRIBUTION (MM) (PCT OF < 2 MM MATERIAL)

NO	SAND V COARSE 2.0-1.0	SAND COARSE 1.0-0.5	SAND MEDIUM 0.5-0.25	SAND FINE 0.25-0.10	SAND V FINE 0.10-0.07	SAND V FINE 0.07-0.05	SILT 0.02-0.005	SILT 0.005-0.002	TOTAL SAND 2.0-0.05	TOTAL SILT 0.05-0.002	TOTAL CLAY < 0.002
1	1.4	2.6	5.3	6.6	3.4	2.4	41.8	13.8	21.8	54.7	23.5
2	0.5	2.2	8.0	9.7	2.9	2.8	37.3	9.3	26.1	52.9	21.1
3	1.9	4.9	13.4	15.6	4.4	3.9	27.9	9.4	44.1	44.9	11.1
4	6.7		15.1	15.8	3.9	3.3	18.7	7.1	44.7	27.8	27.5
5	2.1	4.7	12.6	13.8	4.5	3.6	17.7	6.1	41.3	26.5	32.1
6	0.4		0.6	3.6	4.9	21.9	9.4	3.2	31.4	39.4	29.2
7	3.0	5.3	2.7	3.9	3.0	15.5	7.7	1.1	33.5	41.2	25.3

NO	BULK DENSITY (G/CC) 1/3 ATM MOISTURE ENTIRE CLOD	1/3 ATM MOISTURE < 2 MM IN CLOD	DRY < 2 MM IN CLOD	COLE ENTIRE < 2 MM CLOD	MOISTURE (PCT) RETAINED AT 1/3 ATM < 2 MM IN CLOD	15 ATM < 2 MM SIEVED	AVAILABLE MOISTURE < 2 MM MATERIAL WEIGHT (PCT)	CM/CM OF SOIL	TOTAL SOIL (< 2 MM + FRAGMENTS) WEIGHT (PCT)	CM/CM OF SOIL
1	1.19	1.14	1.52	0.102	19.5	21.2	9.6	11.6	0.132	11.6	0.132
2	1.27	1.14	1.87	0.181	9.9	12.4	8.7	3.7	0.042	3.8	0.043
3	1.26	1.24	1.74	0.120	13.7	14.1	5.7	8.4	0.104	8.5	0.105
4	1.37	1.32	1.82	0.112	14.4	15.3	10.3	5.0	0.066	5.1	0.067
5	1.73	1.72	1.79	0.015	16.9	17.3	12.0	5.3	0.091	5.3	0.092
6	1.56	1.56	1.60	0.009	16.7	16.7	11.2	5.5	0.086	5.4	0.085
7							8.7				

7710 SITE TEN SILT LOAM

ROCK FRAGMENT DISTRIBUTION (MM) (PCT)

NO	DEPTH CM	HORIZON	> 76	76-19	19-4.7	4.7-2.0	TOTAL WT	TOTAL VOL	TEXTURAL CLASS LAB	TEXTURAL CLASS FIELD	TOTAL BULK DENSITY (G/CC)
1	0- 23	A11									
2	23- 38	A12			5.0	6.0	11.0	7.2	SIL	SIL	1.36
3	38- 64	A13		4.9	3.3	6.9	15.1	9.3	SIL	SIL	1.41
4	64- 86	B1		6.3	7.7	8.8	22.8	12.8	SIL	SIL	1.49
5	86-119	B21t		5.1	4.9	9.1	19.2	15.6	SICL	SIL	1.57
6	119-152	B22t		4.2	4.6	11.7	20.5	18.2	SICL	SICL	1.56
7	152-185	B23t		6.2	5.7	6.8	18.7		SICL	SICL	
8	185-196	D3		0.7	6.6	9.6	16.9	11.0	SIL	SICL	1.71
9	196-246	IIC		3.2	5.1	7.7	16.0	12.1	SIC	CL	1.33
									SIL	LFS	

PARTICLE SIZE DISTRIBUTION (MM) (PCT OF < 2 MM MATERIAL)

NO	SAND V COARSE 2.0-1.0	SAND COARSE 1.0-0.5	SAND MEDIUM 0.5-0.25	SAND FINE 0.25-0.10	SAND V FINE 0.10-0.07	SAND V FINE 0.07-0.05	SILT 0.02-0.005	SILT 0.005-0.002	TOTAL SAND 2.0-0.05	TOTAL SILT 0.05-0.002	TOTAL CLAY < 0.002
1	1.6	1.3	1.2	1.0	0.6	0.9	54.8	17.7	6.5	67.5	26.0
2	0.4	1.1	1.1	1.4	0.1	0.5	31.5	15.9	4.7	70.3	25.0
3	1.6	2.0	1.9	1.8	0.8	0.7	49.6	18.1	8.7	65.2	26.0
4	1.1	1.7	1.7	1.7	0.8	1.3	36.9	11.5	8.4	60.0	31.7
5	0.8	1.1	1.7	1.4	0.8	1.5	37.1	8.7	7.2	54.9	37.9
6	1.1	1.8	2.0	1.7	1.0	1.5	37.0	8.8	9.2	57.6	33.2
7	1.5	2.4	2.6	2.5	1.1	2.6	39.6	10.2	12.7	60.3	27.0
8	0.7	0.8	0.8	0.9	0.4	1.3	34.4	10.4	4.9	43.6	51.5
9	0.1	0.3	0.7	3.1	3.7	6.4	26.8	6.7	14.3	71.2	14.5

NO	BULK DENSITY (G/CC) 1/3 ATM MOISTURE ENTIRE CLOD	1/3 ATM MOISTURE < 2 MM IN CLOD	DRY < 2 MM IN CLOD	CCLE < 2 MM CLOD	MOISTURE (PCT) RETAINED AT 1/3 ATM ENTIRE CLOD	1/3 ATM < 2 MM IN CLOD	15 ATM < 2 MM SIEVED	AVAILABLE MOISTURE < 2 MM MATERIAL WEIGHT (PCT)	CM/CM OF SOIL	TOTAL SOIL (< 2 MM + FRAGMENTS) WEIGHT (PCT)	CM/CM OF SOIL
1	1.32	1.30	1.44	0.033	24.6	25.5	10.3	15.2	0.198	15.2	0.198
2	1.45	1.31	1.40	0.018	22.1	26.9	9.9	17.0	0.226	17.0	0.225
3	1.32	1.32	1.36	0.009	25.2	25.2	10.1	15.1	0.199	15.2	0.201
4	1.52	1.50	1.60	0.022	21.4	22.2	12.1	10.1	0.151	10.1	0.152
5	1.53	1.52	1.80	0.056	21.6	22.7	14.1	8.6	0.131	8.6	0.131
6							12.3				
7	1.60	1.60	1.64	0.009	18.8	18.8	10.1	8.7	0.139	8.7	0.139
8	1.32	1.28	1.35	0.019	29.4	33.5	18.5	15.0	0.192	15.0	0.191
9											

7712 SITE TWELVE SILT LOAM

ROCK FRAGMENT DISTRIBUTION (MM) (PCT)

NO	DEPTH CM	HORIZON	> 76	76-19	19-4.7	4.7-2.0	TOTAL WT	TOTAL VOL	TEXTURAL CLASS LAB	TEXTURAL CLASS FIELD	TOTAL BULK DENSITY (G/CC)
1	0- 28	Ap									1.54
2	28- 48	IIB21t		11.5	6.7	4.4	22.6	17.6	SIL	SIL	1.39
3	48- 64	IIB22t			2.6	7.2	9.8	9.8	SICL	SICL	1.45
4	64- 84	IIB23t			0.8	11.3	12.1	7.0	SIC	SIC	1.55
5	84-130	IIB24t			0.5	5.2	5.8	3.4	C	SIC	1.23
6	130-165	IIB25t			1.2	7.7	8.9	4.1	C	SIC	1.22
7	165-180	IIIAb			0.3	7.8	8.1	3.8	SIC	SIC	1.54
8	180-246	IIIBb		4.5	7.4	8.0	19.8	14.8	SIL	SIL	1.56
				5.8	4.0	15.3	25.1	19.9	SICL	SIL	

PARTICLE SIZE DISTRIBUTION (MM) (PCT OF < 2 MM MATERIAL)

NO	SAND V COARSE 2.0-1.0	SAND COARSE 1.0-0.5	SAND MEDIUM 0.5-0.25	SAND FINE 0.25-0.10	SAND V FINE 0.10-0.07	SAND V FINE 0.07-0.05	SILT 0.02-0.005	SILT 0.005-0.002	TOTAL SAND 2.0-0.05	TOTAL SILT 0.05-0.002	TOTAL CLAY < 0.002
1	1.8	2.3					48.1	14.6	11.8	65.7	22.5
2	2.0	2.8	2.4	2.9	0.8	1.6	17.6	8.8	17.0	45.9	37.1
3		0.1	3.1	3.9	2.1	3.0	31.2	12.4	0.6	41.5	57.9
4			0.1	0.1	0.1	0.3	34.0	12.1	0.4	39.9	59.7
5			0.1	0.1			31.0	10.9	0.2	37.8	62.0
6					0.1	0.1	32.7	11.0	0.4	41.7	57.9
7	1.7	1.9		0.1	0.1	0.2	48.4	13.8	10.3	64.8	24.9
8	1.1	1.9	1.9	1.9	1.1	1.9	37.9	10.7	10.7	55.4	33.9
			2.0	2.3	1.1	2.2					

NO	BULK DENSITY (G/CC) 1/3 ATM MOISTURE ENTIRE CLOD	1/3 ATM MOISTURE < 2 MM IN CLOD	DRY < 2 MM IN CLOD	COLE < 2 MM	MOISTURE (PCT) RETAINED AT 1/3 ATM ENTIRE CLOD	1/3 ATM < 2 MM IN CLOD	15 ATM < 2 MM SIEVED	AVAILABLE MOISTURE < 2 MM MATERIAL WEIGHT (PCT)	AVAILABLE MOISTURE < 2 MM MATERIAL CM/CM OF SOIL	TOTAL SOIL (< 2 MM + FRAGMENTS) WEIGHT (PCT)	TOTAL SOIL (< 2 MM + FRAGMENTS) CM/CM OF SOIL
1	1.48	1.46	1.50	0.010	20.6	22.0	10.1	11.9	0.174	11.9	0.174
2	1.39	1.39	1.49	0.022	24.2	26.2	18.0	8.2	0.114	8.1	0.114
3	1.40	1.37	1.58	0.048	30.2	32.0	25.8	6.2	0.085	6.2	0.084
4	1.51	1.51	1.66	0.032	29.2	29.2	25.4	3.9	0.057	3.9	0.057
5	1.17	1.17	1.62	0.114	32.4	32.4	27.8	4.6	0.054	4.5	0.053
6	1.18	1.17	1.61	0.113	31.0	30.3	27.2	3.1	0.036	3.2	0.036
7	1.53	1.45	1.54	0.021	26.3	32.1	9.9	22.2	0.322	22.2	0.315
8	1.51	1.45	1.63	0.039	21.8	25.1	12.9	12.2	0.177	12.3	0.178

APPENDIX F

Impact of Water Conservation on Residential

Septic Tank Effluent Quality

A paper presented at the

Third National Symposium on Individual and Small

Community Sewage Treatment

and published by the

American Society Agricultural Engineers

in

ASAE Publication 1-82

IMPACT OF WATER CONSERVATION ON RESIDENTIAL SEPTIC TANK EFFLUENT QUALITY

Charles A. Cole William E. Sharpe

Failing onsite sewage systems are a serious problem for residents and control agencies. Nearly one-third of the homes in the United States dispose of household wastewaters through individual onsite units and less than one-half will perform satisfactorily over their entire design life of 15 to 20 years (Scalf et al. 1977). Many of these systems are septic tanks followed by seepage beds or trenches. Most systems are considered to be failing when septic tank effluent surfaces above the bed causing aesthetic and potential health problems. Groundwater contamination from malfunctioning systems is also a potential problem.

Domestic water conservation has great potential for reducing the flow of wastewater to the seepage bed (Bennett 1975, Sharpe and Fletcher 1977, Siegrist et al. 1978, Kuhner et al. 1978). However, there has been a lack of data on the amount of water saved by various devices under actual use. Cohen and Wallman (1974) studied a sample of eight homes in the San Diego, California area using watersaving toilets and shower flow controls but measured a reduction of only 8%. However, their evaluations were hampered by small sample size and lower than average showering.

The net effect of water conservation on the hydraulic and pollutant loading of onsite sewage disposal systems has been speculated upon by a number of authors. Sharpe and Fletcher (1977) estimated reductions in wasteflows of 52 percent for a selected combination of watersaving fixtures and assumed that these reductions would allow directly proportional reductions in seepage bed and septic tank sizes. Laak (1977) estimated reductions of 40 percent in absorption bed size as a result of reducing wasteflow volumes by a corresponding amount. Wastewater quality was not considered to be important in arriving at the estimate. Kühner et al. (1978) speculated that conventional watersaving fixtures would have no more than a marginal effect on the organic loading on the seepage bed. Siegrist et al. (1978) however, concluded that reducing flow volumes alone should allow for a proportional reduction in seepage bed size. However, he did not feel that the septic tank size could be reduced on the basis of expected better treatment during reduced peak flows. He also suggested that wasteflow reduction might extend the life of existing onsite systems or alleviate surface discharge in failing systems.

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Siegrist et al. (1978) estimated the theoretical increase in raw waste concentration as a function of water conservation. He assumed the same pollutant contribution before and after conservation devices were installed so that the increase in raw waste concentration was a function of a simple mass balance.

OBJECTIVE

The overall objective of this project was to determine the efficacy of water conservation and seepage bed resting for renovation of failing onsite disposal systems. Septic tank effluent quality was monitored to determine the change in effluent quality from the septic tank as a consequence of water conservation and concomitant wasteflow reduction.

ANALYTICAL TECHNIQUES

The parameters of chemical oxygen demand (COD), total organic carbon (TOC), nonfiltrable residue (Nonf res.), total keljdahl nitrogen (TKN), ammonia nitrogen (ammonia-N), total phosphorous (TP), orthophosphate (Ortho-P), Chloride (CL) and pH were selected for measurement on all the residences in the study. Total and fecal coliform were measured on two residences with devices designed to produce maximum conservation. All parameters were measured according to Standard Methods (1975). Grab samples were taken from each of ten houses two times per week for twelve weeks before and twelve weeks after conservation devices were installed. The period for the pre data was June, July, and August and the period for the post data was November, December, January, and February excluding the Christmas vacation period. The samples were removed from the septic tank 15 to 30 cm under the surface of the liquid in the septic tank between the effluent baffle and effluent pipe. The samples were taken between 9:00 a.m. and 3:00 p.m. using a hand operated suction pump. Each individual system was sampled at about the same time each day. Composite samples of the effluent were not taken because of limited resources for this phase of the project.

PROCEDURES

Different levels of wasteflow reduction were attempted for the demonstration homes by choosing water conservation/wasteflow reduction devices expected to reduce flows by varying fractions. The houses, devices, and predicted reductions are shown in Table 1. The data before water conservation devices were installed were collected from June 2, 1980 to August 20, 1980. The data after the devices were installed were collected from November 3, 1980 to December 17, 1980 and from January 5, 1981 to February 18, 1981. Water use was monitored for individual water using fixtures, outside hose bibbs, and the individual home as a whole. Miscellaneous household water use was determined by subtracting the totals for each of the devices from the total household minus outside bibb use. In two cases unaccounted for outside water use occurred. In these homes water use by individual fixtures was used to determine the wasteflow reduction effects of the water conservation devices that were used.

RESULTS AND DISCUSSION

Concentration Change Evaluation

The arithmetic mean, median, geometric mean, variance, standard deviation and 95% C. I. were calculated for each house and the total group of houses before and after conservation devices were installed. In Table 2, arithmetic mean values and 95% C. I. are shown for selected parameters. Table 3 shows

Table 1. Conservation Devices

HOUSE	CONSERVATION LEVEL[c]	AERATORS	SHOWER HEADS[a]	TOILETS[b]
01	moderate	Bath 1,2 - 1.9 lpm Kitchen - none	Bath 1,2 - Lovo	Bath 1,2 pressure
02	maximum	Bath 1 - 5.7 lpm Kitchen - none	Bath 1 - Lovo	Bath 1 Microphor
03	minimum	Bath 1,2,3 - 1.9 lpm Kitchen - 9.5 lpm	Bath 1,2 - Lovo	Bath 1,2,3 low flush
04	maximum	Bath 1,2 - 1.9 lpm Kitchen - 9.5 lpm	Bath 1 - Navy Bath 2 - Lovo	Bath 1,2 Microphor
05	moderate	Bath 1,2,3 - 1.9 lpm Kitchen - 1.9 lpm	Bath 1 - Nova	Bath 1,2,3 pressure
06	minimum	Bath 1,2,3 - 1.9 lpm Kitchen - 9.5 lpm	Bath 1,2 - Lovo	Bath 1,2,3 low flush
07	maximum	Bath 1,2 - 1.9 lpm Kitchen - 9.5 lpm	Bath 1,2 - Nova	Bath 1,2 Microphor
08	moderate	Bath 1,2,3 - 1.9 lpm Kitchen - 9.5 lpm	Bath 1,2 - Nova	Bath 1,2,3 pressure
09	minimum	Bath 1 - 1.9 lpm Kitchen - 9.5 lpm	Bath 1 - Lovo	Bath 1 Dams
10	minimum	Bath 1,2 - 1.9 lpm Kitchen - 9.5 lpm	Bath 1,2 - Nova	Bath 1,2 Dams
12	minimum	Bath 1 - 1.9 lpm Kitchen - 9.5 lpm	Bath 1 - Lovo	Bath 1 Dams

a/ All shower heads 7.6 lpm maximum at 345 kPa except Navy (1.9 lpm).

b/ Pressure toilet (3.8 - 5.7 l per flush), microphor (1.9 l per flush), and low flush (13.3 l per flush).

c/ Estimated levels of conservation are: 40% for maximum, 20% for moderate, and 10% for minimum.

Table 2. Concentrations of Selected Effluent Parameters Before and After Wasteflow Reduction.

House[a]	Statistic	Parameter (mg/l)									
		COD		TKN		TP		CL		Nonf Res	
		before	after	before	after	before	after	before	after	before	after
Maximum Wasteflow Reduction											
02[b]	mean	551	613	76	90	32	29	105	98	87	108
	95% CI	460-642	553-673	66-87	83-98	27-38	25-33	31-179	76-119	52-112	77-139
04	mean	439	578	90	107	13	19	63	117	123	114
	95% CI	410-467	544-612	77-102	100-114	11-15	17-21	56-69	104-131	94-153	92-137
07	mean	308	402	61	66	9	17	36	62	62	67
	95% CI	266-350	361-444	49-72	57-75	7-12	8-25	32-40	56-68	36-88	60-75
Moderate Wasteflow Reduction											
01	mean	391	451	100	100	20	38	76	88	67	67
	95% CI	364-419	411-490	86-114	103-117	19-22	34-42	22-130	74-103	54-80	60-74
05[c]	mean	272	374	45	58	12	17	500	421	39	57
	95% CI	250-294	341-407	35-56	46-70	9-14	14-21	364-637	310-531	34-44	47-66
08	mean	295	433	65	86	11	24	24	36	70	107
	95% CI	263-327	400-467	52-77	76-96	9-14	6-43	21-27	32-39	61-78	97-118
Minimum Wasteflow Reduction											
03	mean	720	565	59	58	21	27	55	36	303	188
	95% CI	223-1218	503-627	49-69	51-64	16-27	22-31	4-113	30-43	77-684	139-237
06[b,c]	mean	924	658	70	57	13	16	1341	1022	167	109
	95% CI	503-1344	561-756	51-89	51-62	9-17	11-21	473-2210	710-1334	98-235	90-127
09[b]	mean	421	521	62	61	17	12	32	66	46	57
	95% CI	380-463	476-565	54-71	53-68	15-19	8-16	28-36	34-99	40-52	47-67
10[b]	mean	507	486	116	73	34	49	64	54	119	108
	95% CI	460-553	464-509	97-134	68-79	31-37	40-59	58-70	51-58	87-152	87-127

[a] Houses 2, 4 and 7 received maximum conservation, 1, 5 and 8 moderate conservation, and 3, 4, 9, and 10 minimum water conservation (see Table 1).

[b] Septic tank pumped between the before and after period.

[c] Water softener in use. Regeneration salt changed in House 5.

the total and fecal coliform results including arithmetic and geometric means.

Table 3. Total and Fecal Coliform Concentrations Before and After Wasteflow Reductions.

House	Statistic	Parameter (MPN/ml)			
		Total coliform		Fecal coliform	
		before	after	before	after
04	mean	77,000	61,000	3,000	11,000
	geo mean	59,000	45,000	1,600	6,900
	95% CI	51,000-100,000	41,000-81,000	1,400-5,200	5,200-18,000
07	mean	82,000	270,000	920	13,000
	geo mean	51,000	152,000	470	2,500
	95% CI	51,000-110,000	120,000-430,000	510-1,300	1,300-25,000

The data presented in Table 2 reveal some interesting before and after differences in effluent quality. For the houses with maximum wasteflow reduction there was a concentration increase in nearly all parameters. House 2 did not show an increase for the parameters total phosphorus and chlorides, but the septic tank at house 2 was pumped at the completion of the before data collection period. A larger septic tank storage capacity for clarified effluent may have accounted for the small decreases in observed concentrations of these parameters. House 4 did not show an increase in nonfiltrable residue but other parameters increased.

The moderate level of water conservation also produced consistently larger concentrations of all effluent parameters after the installation of wasteflow reduction equipment. The only decrease was for chlorides at house 5. An ion exchange water softener was utilized at this house and chloride results were therefore very high and variable. In addition regenerate salt and regenerate frequency was changed during this study.

The minimum wasteflow reduction homes are difficult to evaluate because all but one had their septic tanks pumped between the measurement periods. The removal of accumulated solids during pumping is likely to have resulted in lower concentrations of at least the organic parameters because of increased hydraulic detention time. The tanks at houses 9 and 10 had to be emptied in order to install alternate seepage beds as part of the remedial treatment at these homes. The tank at house 6 was pumped at the owner's request in order to temporarily alleviate the serious surface discharge of septic tank effluent. Although the pumping of the septic tanks is a variable that cannot be accounted for, it is unlikely that large increases in the concentrations of pollutants in the septic tank effluent would have been observed in these systems because of the minimal wasteflow reduction achieved. The data from house 3 indicates no consistent trend to increased concentrations for the effluent parameters for this system. This result is consistent with the results from houses 6, 9, and 10. It would appear that changes in the concentration of most effluent parameters was small for the minimum wasteflow reduction homes. Such changes were probably small enough to be masked by septic tank pump out and normal variations in septic tank effluent quality.

Higher concentration of pollutant parameters in the maximum and moderate wasteflow reduction houses was achieved after the wasteflow reduction devices were installed. This was not the case for the minimum wasteflow reduction homes where higher concentrations most frequently occurred before device installation. Septic tank effluent discharged to soil absorption

fields where maximum and moderate conservation devices were employed contained higher concentrations of pollutants than effluent discharged in the same systems without devices and systems receiving minimal wasteflow reduction devices.

Use of ion exchange water softeners on houses 5 and 6 increased the chloride concentration of septic tank effluent by at least tenfold over houses not using softeners. Heavy concentrations of ion exchange water softeners in residential areas served by onsite sewage systems could be expected to result in increased chloride levels in groundwater.

Total and fecal coliform bacteria were monitored in houses 4 and 7 both of which had maximum wasteflow reduction. Arithmetic and geometric mean, concentrations of bacteria were greatest after installation of the wasteflow reduction hardware with the exception of total coliform concentration at house 4. There is no readily apparent explanation for the house 4 total coliform results.

The Mann-Whitney test, a nonparametric test for median population difference, was used to test the research hypothesis that the post period pollutant concentrations were greater than the pre period. The Mann-Whitney test was used because the data were not normally distributed. These values are shown in Table 4 for the selected parameters of Chlorides, TOC, Nonf Residue, Total-P, TKN, and Fecal Coliform. The median values were used for the comparison since they are less affected by outlying values.

The Mann-Whitney tests indicate a highly significant increase in the after values for most parameters. The probability that the median values after conservation are greater than before conservation are much greater for the maximum wasteflow reduction households than for the other households. The moderate conservation household group probability values are intermediate. The minimum group probability are the lowest. These results are consistent with others in this study that show the greatest impact on septic tank effluent occurs as a result of the installation of maximum wasteflow reduction devices.

Parameter Correlation

Spearman correlation coefficients were calculated for the parameters before and after conservation devices were installed. The Spearman correlation was used since the data did not follow a normal distribution. Table 5 contains a summary of the Spearman correlation coefficients for all the parameters measured in the septic tank effluent before water conservation devices were installed. Good correlations (>.70) were obtained between ammonia-N and TKN, ortho-P and total-P, and TOC and COD for the before conservation device period. For data collected after device installation similar correlations were found (not shown here). It appeared as though the presence or absence of water conservation devices had little noticeable effect on these correlations.

A very good correlation was obtained between COD and TOC especially on the before data where the Spearman coefficient was .90. Therefore, TOC the easier parameter to measure, was chosen for comparisons and is recommended for future studies. TKN with ammonia-N and total-P with ortho-P also resulted in high correlation. These were probably to be expected but it was felt that verification was necessary because of the possible impact of organic compounds on the apparent predominant inorganic fractions. Use of ammonia-N and ortho-P would therefore be recommended for future studies. There was a modest correlation of other parameters but none were high enough that elimination of one or more parameters could be recommended from future studies. Total coliform did not correlate well with fecal coliform which was surprising. It was most likely due to the high variability and low sample size in the data.

Table 4. Before and After Median Values and Mann-Whitney Test Results for Selected Septic Tank Effluent Parameters.

House	CHLORIDE (mg/l) Before	After	α(<)	TOC (mg/l) Before	After	α(<)	NONF. RESIDUE (mg/l) Before	After	α(<)	TOTAL P (mg/l) Before	After	α(<)	TKN (mg/l) Before	After	α(<)	FECAL COLIFORM (MPN/ml) Before	After	α(<)
Maximum wasteflow reduction																		
02	54	86	<.0001	147	212	.0107	50	91	.0017	32	29	--	72	90	.0047	--	--	--
04	58	117	<.0001	118	152	.0199	105	99	--	12	18	<.0001	82	103	.0016	2300	7900	.0002
07	32	61	<.0001	94	132	.0019	49	68	.0004	8	10	.0158	54	65	.0333	490	2250	.0023
Moderate wasteflow reduction																		
01	50	82	<.0001	143	152	.2988	60	63	.1070	21	36	<.0001	100	106	.0227	--	--	--
05	482	338	--	90	107	.0236	37	50	.0016	10	16	<.0001	40	52	.0039	--	--	--
08	23	35	<.0001	88	138	<.0001	63	108	<.0001	9	16	.0007	58	87	<.0001	--	--	--
Minimum wasteflow reduction																		
03	24	33	.0015	167	200	.0664	84	160	.0036	18	22	.0207	54	58	.3311	--	--	--
06	434	791	.0325	152	254	.1140	74	97	.1782	9	13	.0017	52	55	.4324	--	--	--
09	31	52	<.0001	134	162	.0534	43	52	.0392	18	10	--	62	58	--	--	--	--
10	69	55	--	188	152	--	96	96	--	35	43	<.0001	108	74	<.0001	--	--	--

Table 5. Spearman Correlation Coefficients (nonparametric) Before Device Installation.

	COD	Nonf. Res.	TKN	Ammonia N	TP	Ortho P	CL	pH	Total Col.	Fecal Col.
Nonf. Res.	.57									
TKN	.47	.38								
Ammonia N	.51	.39	.78							
TP	.50	.19	.40	.51						
Ortho P	.42	.15	.31	.52	.75					
CL	.18	.06	.15	.17	.09	.11				
pH	-.08	.02	.19	.26	.22	.22	-.11			
Total Col.	.05	-.05	-.03	-.02	.16	-.11	.15	.01		
Fecal Col.	.27	.25	.34	.29	.36	.38	.34	.43	.30	
TOC	.90	.59	.54	.53	.55	.46	.17	-.14	.05	.38

Septic Tank Efficiency

Chloride is a conservative parameter that has been used as a tracer of sanitary pollution. Chloride would be expected to remain unchanged as it passed through a septic tank and therefore the same mass entering in solution should leave in solution. Table 6 is a summary of the recorded water use reductions as measured by water meters, the expected ratio for change in concentration and the actual ratio measured in the effluent.

The measured ratio of chloride in the septic tank effluent was not the same as that expected from theoretical prediction; however, given the variability inherent in most septic tank effluent parameters this was expected. The chloride ratios for all systems with the exception of house 10 are greater than the theoretical. Maximum chloride concentration increases occurred in systems with maximum wasteflow reduction. The magnitude of the differences between the theoretical and the actual varied from 0.04 to 0.49. It appears that chlorides are concentrated in the septic tank effluent more than a volumetric comparison of wasteflow ratios would indicate. However, seasonal changes on chloride to water use may also have caused the unexplained difference.

The parameters TOC and Nonf Residue are two measures that would be expected to reflect the organic removal efficiency of the septic tank. Where the ratio of TOC and/or Nonf Residue is less than that of chloride it would suggest that the relative removal of organics increased with wasteflow reduction. This is true because, although both chloride and organics would increase in concentration as a result of wasteflow reduction, the organics would not increase proportionally. The TOC ratios in Table 6 are all less than the chloride ratio with the excention of house 8. All the maximum conservation systems have TOC ratios considerably less than their respective chloride ratios indicating improved organics removal in the systems as a result of wasteflow reduction. Unfortunately, the Nonf Residue do not show a similar result; however, two of the three maximum conservation systems show smaller ratios. Although generalization from such a small sample is admittedly unwise, it appears that organics removal in the maximum reduction homes may have been improved.

SUMMARY AND CONCLUSIONS

The installation of wasteflow reduction devices in homes experiencing malfunctioning septic systems resulted in estimated wasteflow reductions of from 16.2 percent to 39.8 percent depending upon the types of equipment installed. Co: ntrations of most septic tank effluent parameters were significantly increased in homes after installation of wasteflow reduction equipment. Those homes receiving maximum wasteflow reduction equipment had the highest and most significant increases in septic tank effluent pollutant concentrations. There is some evidence that organics removal in septic tanks was improved in those systems getting maximum level equipment. Predicted increases in concentration of the conservative effluent parameter, chloride, were much less than those actually observed.

Correlations between effluent parameters before and after installation of wasteflow reduction hardware were the same indicating no wasteflow reduction affect. A strong correlation between TOC and COD, ammonia-N and TKN, and ortho-P and total-P indicates that the simpler test could be substituted for the more difficult determination in future investigations of septic tank effluent quality.

Two of the study systems employed ion exchange water softeners to mollify the effects of hardness in the domestic water supply. These systems had septic tank effluent chloride concentrations more than 10 times greater than those homes without ion exchange water softeners. High densities of

Table 6. Comparison of Percent Wasteflow Reduction With Before and After Concentration Ratios for Selected Effluent Parameters (Median Values).

House	% Wasteflow Reduction (gpcd)	Theoretical Ratio	Actual Ratio		
			CL	TOC	TSS
maximum wasteflow reduction					
02	-29.1	1.41	1.59	1.44	1.82
04[a/]	-34.0	1.52	2.01	1.29	-1.06
07	-39.8	1.66	1.91	1.40	1.39
moderate wasteflow reduction					
01	-17.4	1.21	1.64	1.07	1.05
05[b/]	-20.7	1.26	--	1.18	1.35
08	-28.1	1.39	1.52	1.57	1.73
minimum wasteflow reduction					
03	-16.2	1.19	1.38	1.20	1.92
06[a,b/]	-27.6	1.38	--	1.66	1.31
09	-38.9	1.64	1.68	1.20	1.21
10	-24.7	1.33	-1.21	-1.19	0

a/ Wasteflow based on sum of shower, laundry and toilet use only.

b/ Chloride values excluded because of the presence of ion exchange water softener.

residences with ion exchange softeners and on-lot sewage systems could result in increased chloride levels in groundwater.

Although this study has clearly demonstrated that the installation of waste-flow reduction hardware will result in higher concentrations of pollutants in septic tank effluent, mass loading should remain constant or be reduced somewhat by virtue of improved septic tank treatment. Moreover any increase in pollutant concentration should be more than offset by the significant decrease in hydraulic load on the septic tank-soil absorption system.

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APPENDIX G

Effluent Ponding Levels in Soil Absorption Areas at the Eleven Sites During the Project

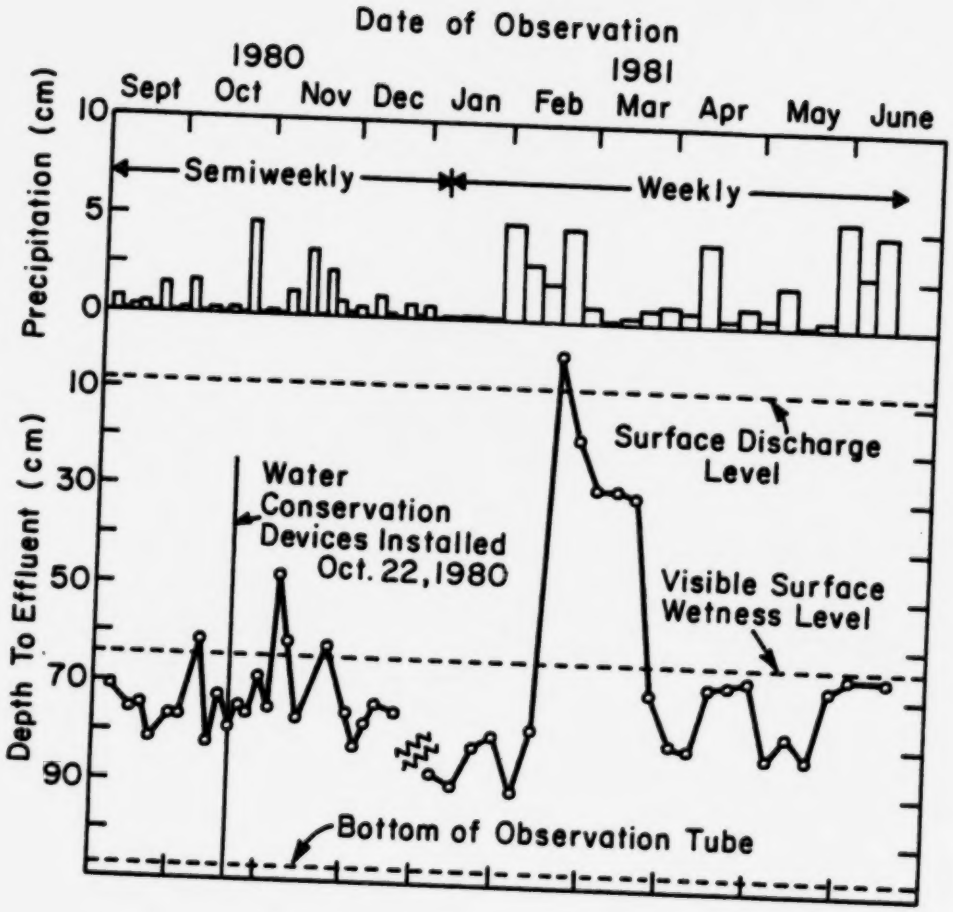

Figure G-1. Effluent ponding levels in the soil absorption area and semiweekly or weekly precipitation for site 1.

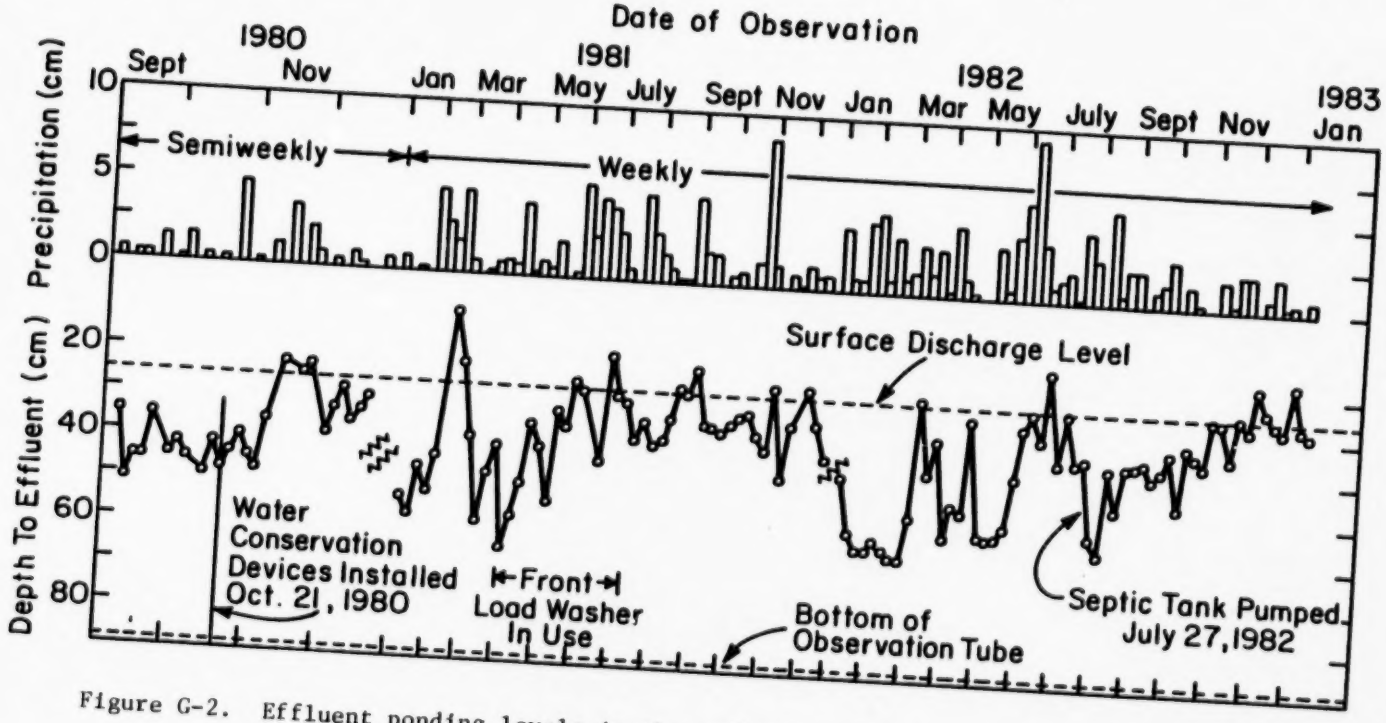

Figure G-2. Effluent ponding levels in the soil absorption area and semiweekly or weekly precipitation for site 2.

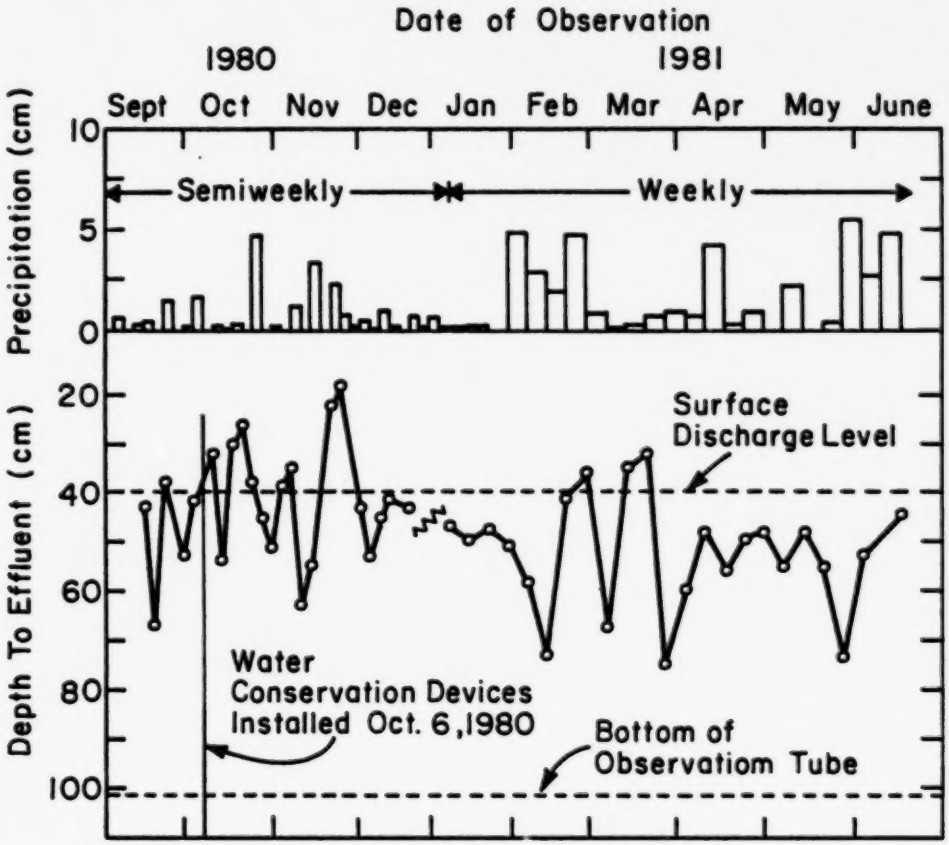

Figure G-3. Effluent ponding levels in the soil absorption area and semiweekly or weekly precipitation for site 3.

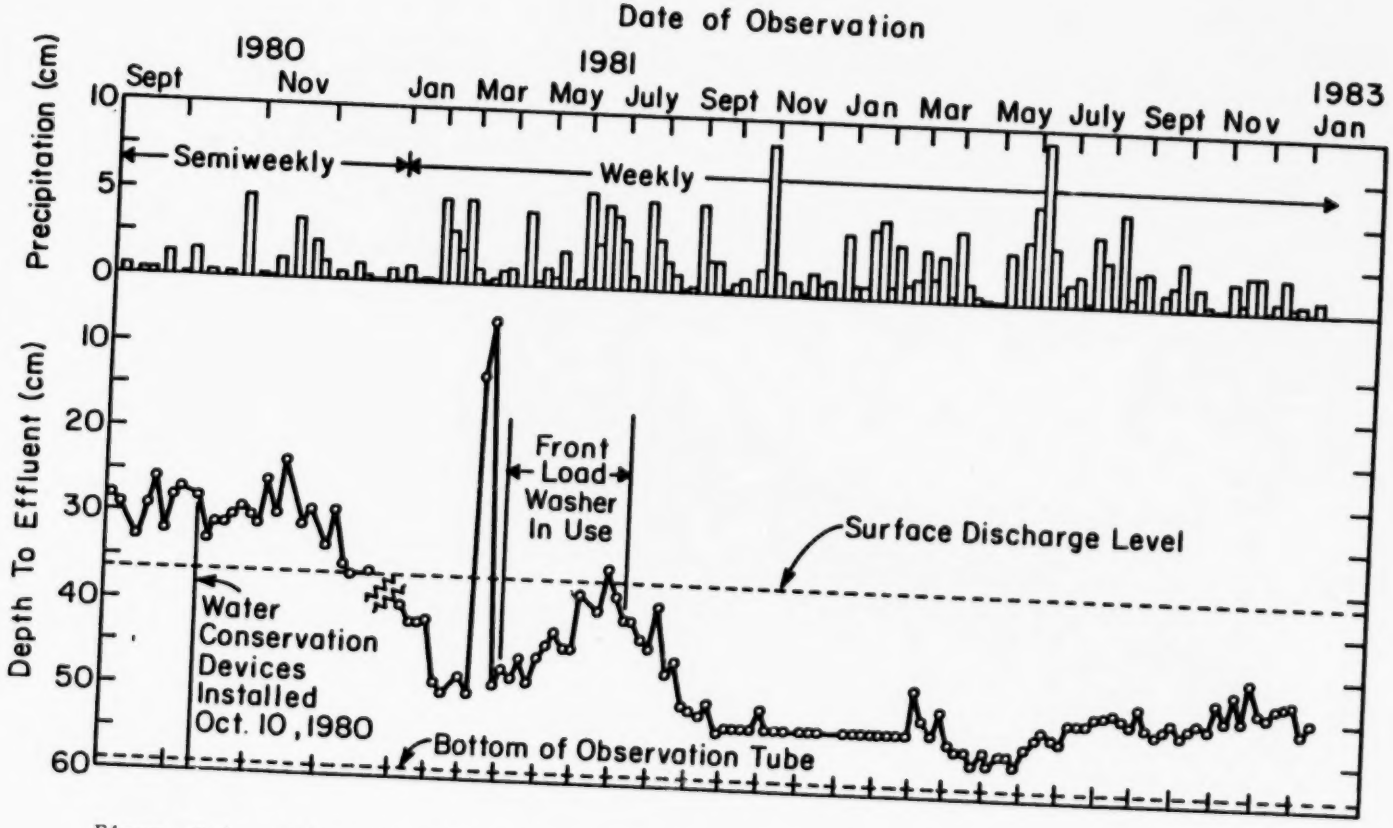

Figure G-4. Effluent ponding levels in the soil absorption area and semiweekly or weekly precipitation for site 4.

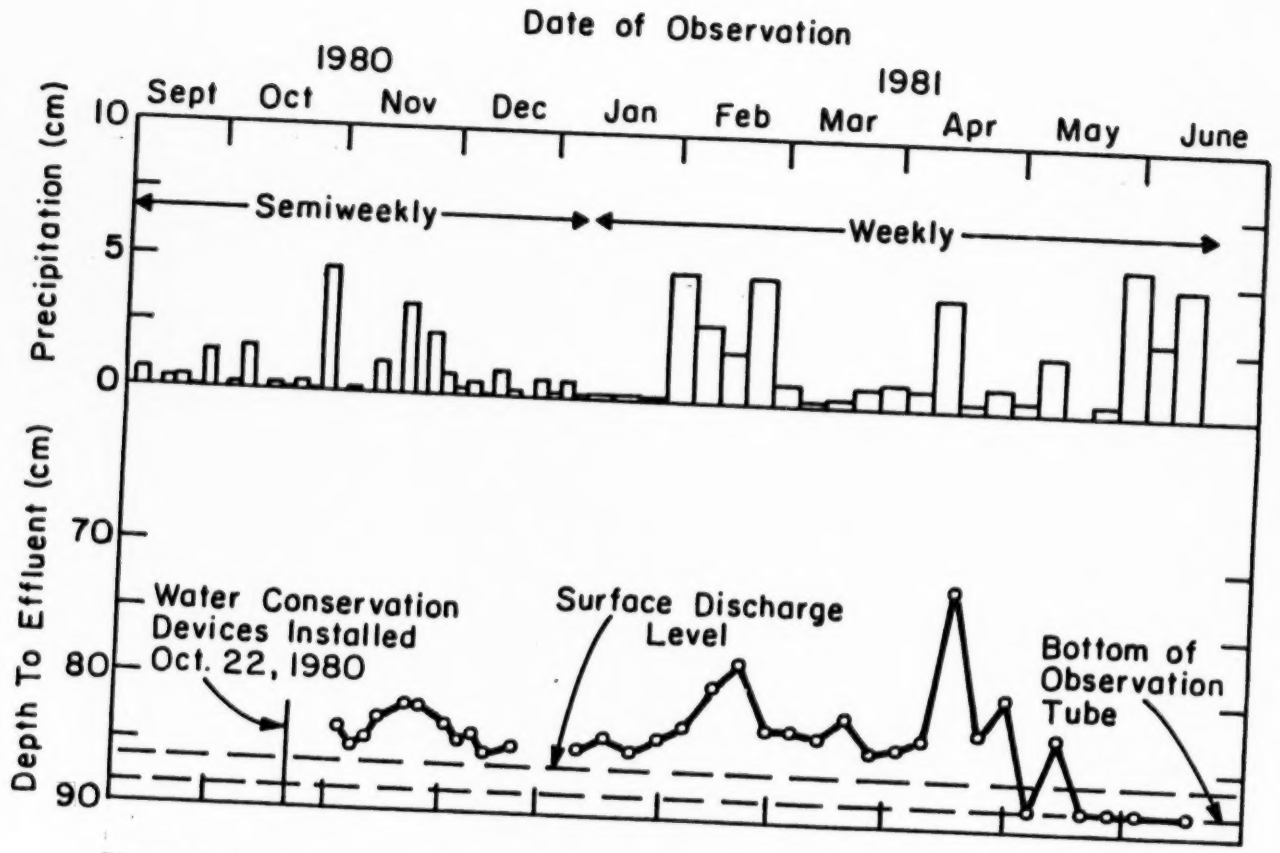

Figure G-5. Effluent ponding levels in the soil absorption area and semiweekly or weekly precipitation for site 5.

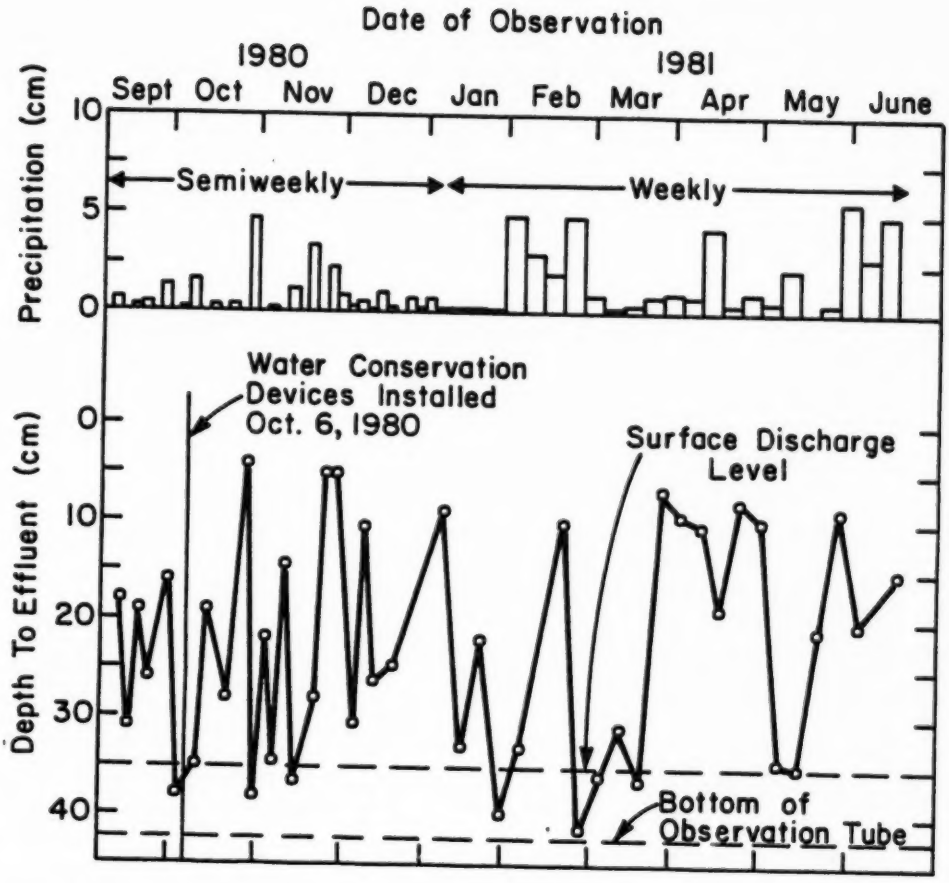

Figure G-6. Effluent ponding levels in the soil absorption area and semiweekly or weekly precipitation for site 6.

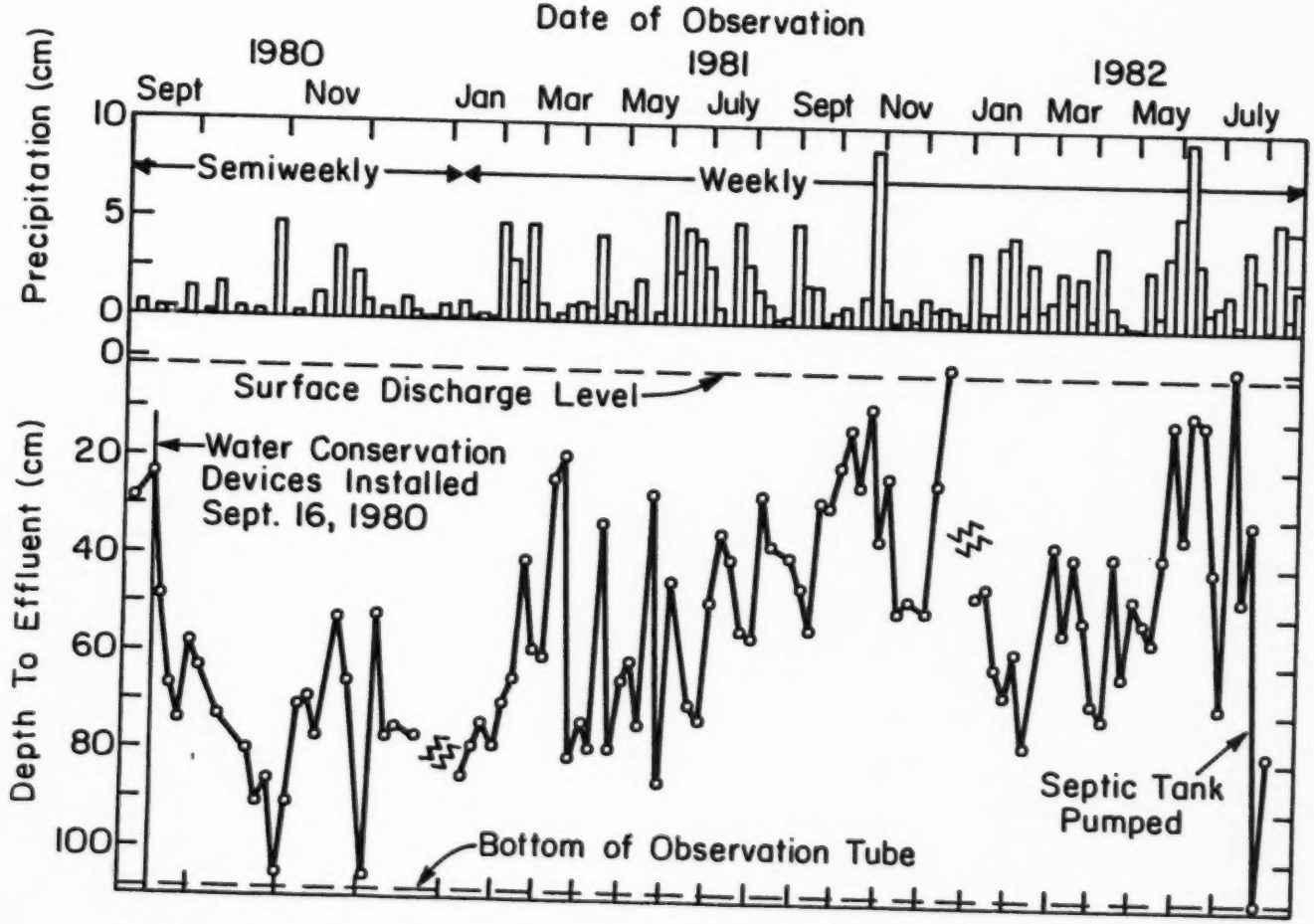

Figure G-7. Effluent ponding levels in the soil absorption area and semiweekly or weekly precipitation for site 7.

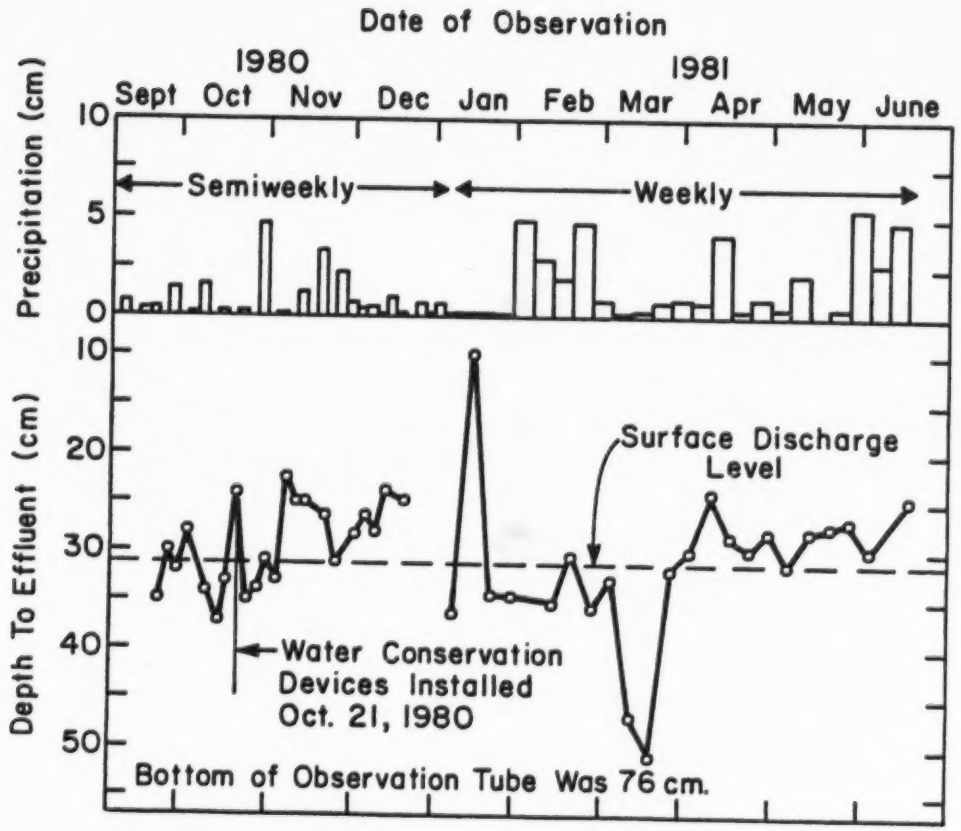

Figure G-8. Effluent ponding levels in the soil absorption area and semiweekly or weekly precipitation for site 8.

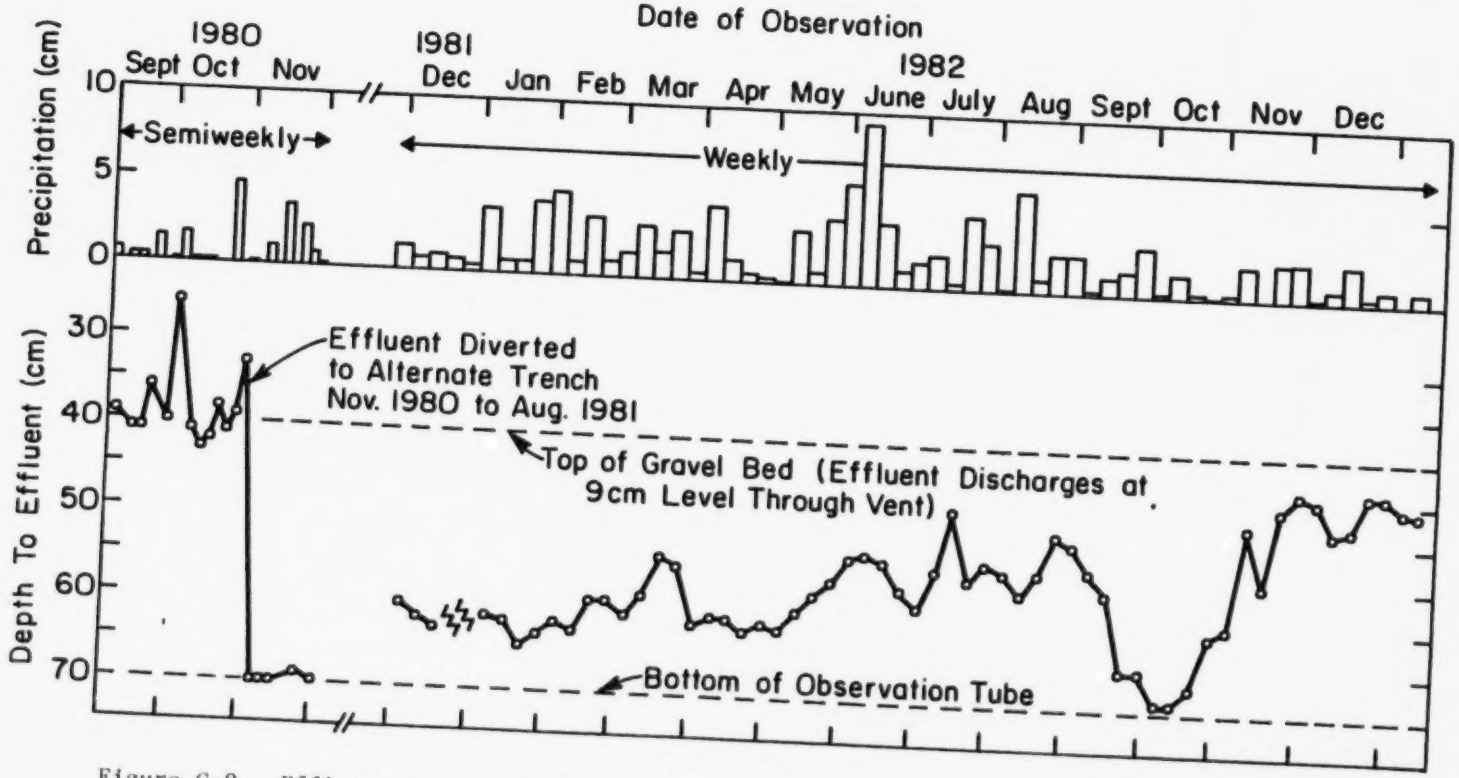

Figure G-9. Effluent ponding levels in the soil absorption area and semiweekly or weekly precipitation for site 9.

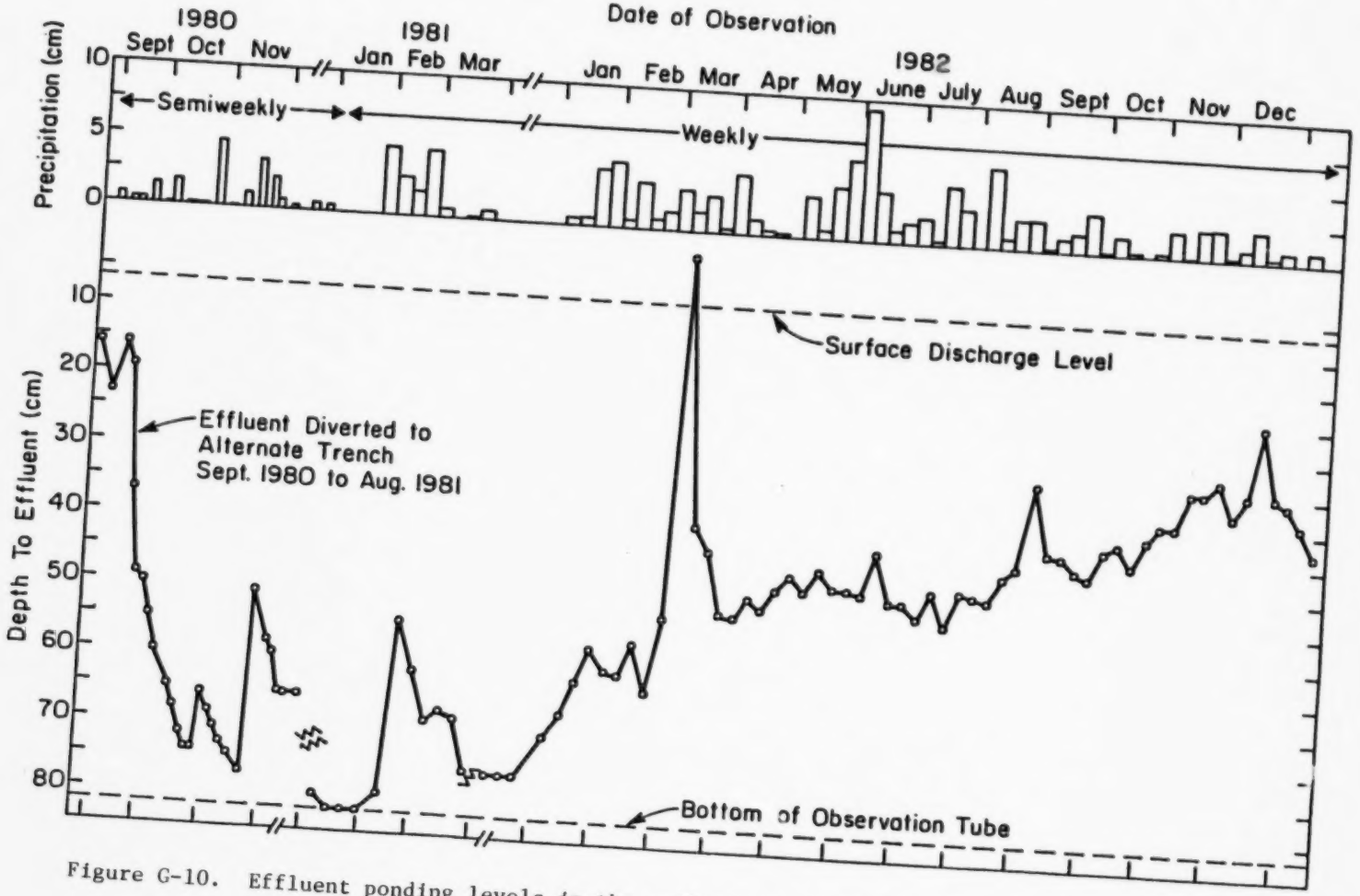

Figure G-10. Effluent ponding levels in the soil absorption area and semiweekly or weekly precipitation for site 10.

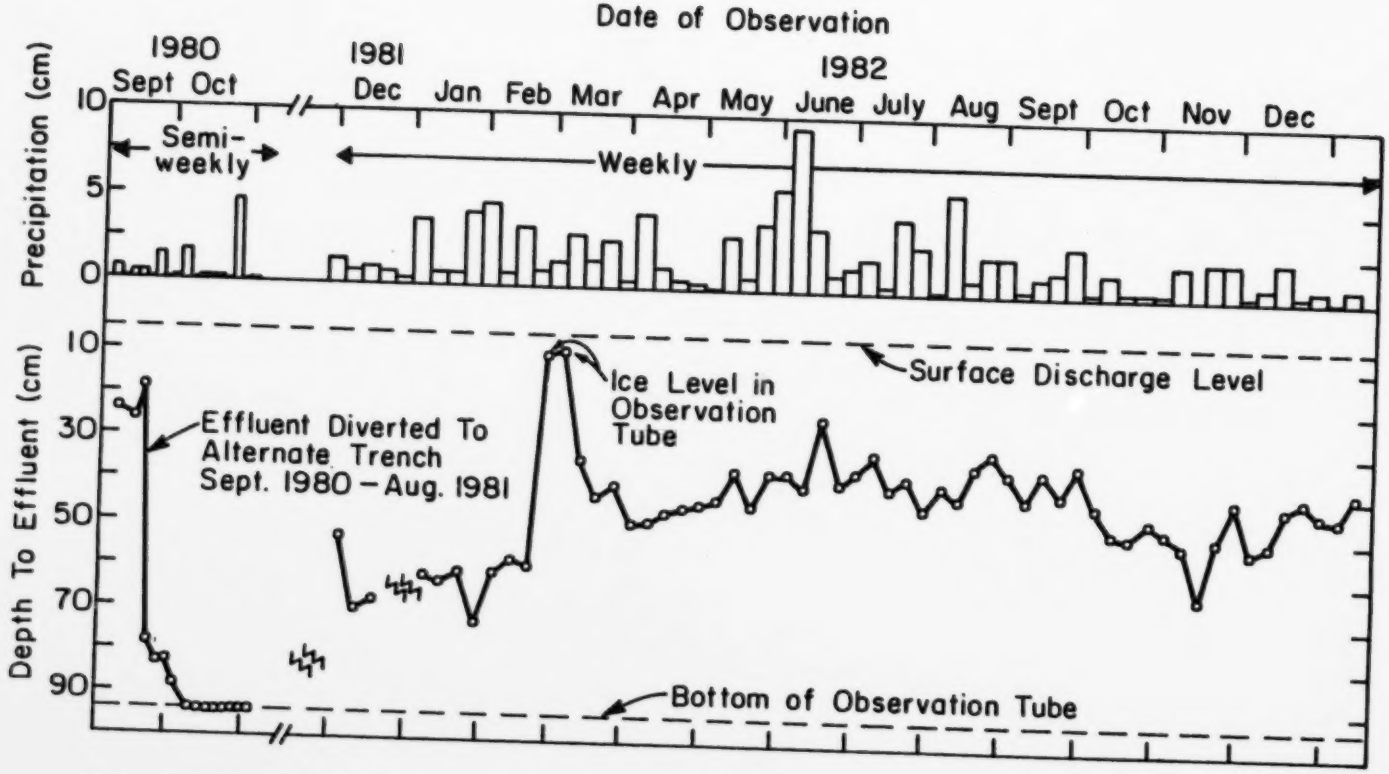

Figure G-11. Effluent ponding levels in the soil absorption area and semiweekly or weekly precipitation for site 12.